IMPACT OF NEW BUS LINES ON WORK TRIPS
A CASE STUDY FOR NAGPUR

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by

SHANTI PRASAD NAMBALLA

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CERTIFICATE

Certified that the work on 'Impact of New Bus Lines on Work Trips - A Case Study for Nagpur' by Shanti Prasad Namballa has been carried out under my supervision and that this work has not been submitted elsewhere for a degree.

Dated : May, 1982

(B.R. Marwah)
Assistant Professor
Department of Civil Engineering
Indian Institute of Technology, Kanpur

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S.P. NAMBALLA

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$(ADT)_s$ - Average daily traffic for s type vehicles where s=2 for scooters, mopeds and motorcycles
s=4 for cars

$(PVDL)_s$ - Percentage of volume measured for s type vehicles.

$(TTRD)_{mDs}$ - Total trip distribution for trips made from m th zone to destination D by s type vehicle.

$(OTRD)_{mDs}$ - Observed trip distribution for trips made from m th zone to destination D by s type vehicle.

$(SSIZE)_s$ - Sample size of s type vehicle

$(UFACTOR)_{ik}$ - Utility factor of i th zone touching route k.

$(LENGTH)_{ik}$ - Length of route k coinciding with the perimeter of i th zone.

$(FDEM)_{iks}$ - Final demand in i th zone from owners of s type vehicles on k th route.

$(LINKLF)_{pqk}$ - Link load factor of the link between nodes p and q on k th route.

$(FLOW)_{pqk}$ - Flow on the link p-q on k th route.

$(NBUS)_k$ - Number of buses on k th route.

$(CAPBUS)_k$ - Capacity of bus on k th route

$(DEM)_{pnk}$ - Demand at p th node on n th link of k th route

$(ALF)_k$ - Average load factor of k th route

$(NLINK)_k$ - Number of links on k th route

$(OCRATIO)_k$ - Occupancy ratio of k th route

$TOCOST)_{sk}$	- Unit total cost of travel for a person owning s type vehicle in Rs. per passenger per Km.
$(UMCOST)_{s}$	- Unit maintenance cost in Rs. per Km. of s type vehicle
$MNCHRG)_{s}$	- Monthly maintenance charges of s type vehicle
$(TLENGTH)_{s}$	- Average trip length of s type vehicle
$(OCPVEH)_{s}$	- Operating cost of s type vehicle in Rs./Km.
(PRICE)	- Price of fuel in Rs. per litre.
$(AVDC)_{s}$	- Average distance covered per litre of fuel consumed in Kms. per litre for s type vehicle.
$(SAV)_{sk}$	- Unit savings for s type vehicle owners but travelling by bus in Rs. per passenger per Km.
C	- Bus capacity
F_2, F_4	- Fractions of travellers using two and four-wheelers respectively.
K_B, K_2, K_4	- Average triplength made by bus, two and four-wheelers respectively.
L_B, L_2, L_4	- Total fuel consumed by bus, two and four-wheelers respectively.
P_B, P_2, P_4	- Total passengers per rush hour trip on bus, two and four-wheelers respectively.
n_B, n_2, n_4	- Efficiency of bus, two and four-wheelers respectively.

$(LLINK)_{pqk}$ - Link length between nodes p and q on k th route

$(LROUTE)_k$ - Total length of route k

$(RTIME)_k$ - Roundtrip time of the bus on the k th route

$(MBUSP)_k$ - Mean bus speed on the k th route

$(LDTIME)_D$ - Layover time at the destination D

$(HWAY)_k$ - Headway of buses on the k th route

$(AWATIM)_k$ - Average waiting time on route k when NBUS buses are being plied.

$(BTRTIM)_k$ - Travel time by bus on k th route

$(TRPTIM)_k$ - Travel time by s type vehicle on k th route

$(MPVSP)_{sk}$ - Mean speed of s type vehicle on k th route

$(MTRLEN)_s$ - Mean triplength made by s type vehicle owner on k th route

$(ADTIME)_{sk}$ - Additional travel time spent by a person owning s type vehicle, but travelling by bus on route k

$(UOC)_k$ - Unit operating cost in Rs. per passenger per Km.

$(OPCOST)_k$ - Average operating cost of bus in Rs. per Kms. on k th route

$(UCTIME)_s$ - Unit cost of time of a person owning s type vehicle in Rs./hour

$(INCOME)_s$ - Monthly income of a person owning s type vehicle

$(DAY)_s$ - Number of working days in a month

$(HOUR)_s$ - Number of working hours a day

$(AUCOST)_{sk}$ - Additional unit cost incucurred by a passenger owning s type vehicle but travelling by bus on ro

SYNOPSIS

The analysis of energy consumption in an urban transportation system is complex in nature because of the several factors involved. The total energy consumption of this system being a function of the volume of traffic on the existing road network, can be reduced by effecting a modal shift of the road users so that the number of vehicles are reduced.

In the case study undertaken for the city of Nagpur, the existing bus system is unable to cater to the peak hour demand for various destinations. Hence the effect of an improved bus system linking the various residential zones of the city with the Industrial estate is studied.

The data is collected for the trip distribution matrix and three routes are identified for plying the buses. so as to connect the residential zones having high demand with the Industrial estate. The optimal number of bus trips are determined based on the minimum travel cost criteria. The additional travel time resulting due to trips made by bus, has been assigned a cost on the basis of the income of different types of vehicle owners. Since the value of this time may not be the same during all hours of the day different weights are assigned to this cost. The modal shift is also varied as it is likely that there might

not be a 100% shift on implementation of such a system. The optimal number of buses are determined for various levels of modal shift and weights. The effect of these parameters on various costs are studied and the savings resulting from such a modal shift are computed for all the three routes.

A dispatching policy is suggested for the optimal number of buses such that the total waiting time of the passengers is reduced.

1. INTRODUCTION

1.1. General

Since the 1973-74 oil crisis there has been considerable interest in energy futures and in the analysis of the sensitivity of transportation related energy consumption to alternative transportation and landuse policies. Traditionally, the uraban transportation planning process has not dealt with the availability of fuel. Before the oil crisis, there appeared to be little need to develop urban transportation plans or strategies to cope with this possibility. Since the oil crisis, planners have begun to re-evaluate the urban transportation planning process in the light of dwindling world wide oil resources, and its impact on urban travel behaviour.

The propensity for an individual or a household to change travel behaviour under energy constraints appears to be most heavily influenced by income. Lower income groups generally have less travel flexibility, make fewer discretionary trips and are more likely to shift to a different mode of transportation due to a hike in oil prices.

Transport demand has two dimensions. First, it relates to the number of people to be carried and secondly, the average distance to be covered. Broadly, the number of people to be carried is correlated to the size of the population and the level of economic activity, whereas the average load

depends on the location of people and their activity in urban area spaces. The quantum of transport demand, expressed in passenger-kms is thus closely linked with landuse patterns and locations of economic activities.

In our country the Transport Industry consumes nearly a third of the country's commercial energy out of which 81 % is oil. This turns out to be 30 million tonnes of which more than two-thirds is imported (NTPC, 1980). Hence there is no doubt that energy conservation will be the most important guiding principle in the framework for determining the future growth of our transport system.

Our country has an extensive road network which serves all types of surface transport vehicles viz., trucks, buses, cars, animal-drawn carriages, scooters and bicycles. In view of financial constraints, oil shortages and also in the interest of optimising output of the existing road system it is necessary that the vital links be identified so that they may be provided with an efficient transportation system and the missing links introduced to reduce the travel time.

1.2. Statement of the Problem

The development of a transportation system must be managed by considering the optimum use of the natural resources. As the construction of new facilities becomes

less feasible, the better operation of existing systems is a key to better system management.

In any urban region the traffic flow on a road depends on several parameters viz., concentration, landuse patterns, type of vehicles, number of traffic signals encountered along a route, and road characteristics. Our primary aim being to minimize the overall fuel consumption, it can be effected by varying any of the above mentioned parameters but the feasibility of these variations is considerably restrained. Even though efficient landuse and better roads as vital links seem to be better tools in traffic management their implementation is constrained in already developed cities.

It is generally observed in medium sized cities that the existing transportation system is unable to cope with the peak hour demand. It is also obvious that provision of an efficient transit system will require immense investment, but the demand variations being sharp it is not possible to break even the operating costs. Another fact generally observed is that, in such cities the landuse pattern is well defined as far as residential and industrial zones are concerned and during the peak hours the flow is from the residential to the industrial zones and vice versa. This flow generally consists of different modes, most of which are privately owned vehicles, the reason being the inability of

the current transit system to cater to the peak demand. It is also noticed that a major proportion of the traffic flow comprises of two-wheelers viz. , seooters, motor-cycles, mopeds and bicycles. The flooding of the vital roads with different categories of vehicles where separate lanes do not exist, results in increasing the concentration. In such circumstances provision of an improved transit system results in a modal shift of trips by private vehicles to the public transit system. The level of service of this system decides the impact on the modal shift and also results in relieving the congestion, economy to the passengers and overall saving in energy which need to be investigated.

1.3. Objectives of the Study

Any change for improvement of a transit system involves a colossal financial investment. In most of the cities where the growth has stabilized, the development has taken place in a haphazard manner, landuse policies seem tobe ineffective. Similarly, improvement of road characteristics like widening are also restricted. Since most of the trips are mandatory during the peak hour, the idea of restricting the traffic flow, say, by diversions is ruled out. Hence the option that seems feasible is by providing an efficient bus system on the routes linking the industrial zones with the residential zones, so as to enable a modal shift of the private vehicle users to the public system thus reducing the overall fuel

consumption, economising the travel cost and relieving the congestion.

In our country little information is available for any medium sized city, concerning the various characteristics of the work trip makers, viz., mode of travel, trip length, socio-economic status, the conservation of fuel and the amount spent on these trips. Before providing an extension of the transit system in any area, it is preferable to study the impact of the transit service on the users, their environment and the energy consumption.

1.4. Scope of the Study

It is observed that most of the peak hour trips are work trips and hence are mandatory. A case of work trips from residential to industrial zones has been cited in this study. In any city this is true for all commercial zones where any business activity takes place. Thus for a given city the commercial and residential zones and the vital links connecting them can be identified to study the feasibility of an improved peak hour bus transit system and the savings resulting therein.

The study has been restricted to the flow from industrial to residential zones because of the time involved in data collection for the whole city.

The salient features of the study are as follows :-

(1) Nagpur city has been chosen for the case study as it represents a majority of the cities in India with a population of over 1 million.

(2) The industrial area considered is not connected by a bus service.

(3) Work trips made to this area by cars, scooters, motor-cycles and other two-wheelers have been analysed to determine the trip origins, travel time and the fuel consumption.

(4) Based on this observed travel pattern three different routes have been designed to meet the existing travel demand.

(5) The impact of these bus routes on travel time, costs and fuel consumptions has been evaluated for different levels of modal shifts.

(6) The optimal number of buses on each route is determined based on the minimum total cost.

(7) A mathematical model is formulated to choose the dispatch times in such a manner so as to minimize the total waiting time of the passengers.

1.5. Organisation of the Report

The study is represented in the following sequence : Chapter 2 reviews the literature on energy consumption models for urban transportation. Chapter 3 deals with the mode

of data collection and its compilation. The analysis of costs from the collected data, design of routes and their impacts is presented in Chapter 4. In Chapter 5 the dispatching policies model is formulated. The results of the analysis and the conclusions drawn are presented in Chapter 6.

2. ENERGY RELATED MODELS FOR URBAN TRANSPORTATION-A REVIEW

2.1. General

The need to reduce energy consumption, air pollution and traffic congestion caused by automobiles has stimulated widespread discussion of the feasibility and desirability of diverging large numbers of urban area private vehicle owners to mass transit. Much of the energy consuming activity of a regional systems takes place in its urban areas. Eventhough a large percentage of residential, commercial and transportation energy use is consumed by the urban communities, Romanos and Hatmaker (1979) have shown that the significance of more rational urban design and of reorganisation of spatial structures and activities in conserving energy has not been widely recognized. However, in the recent past considerable work has been done in this direction and several mathematical models have been developed, but the approach has been different in each case. The models are based on the landuse traffic flow characteristics or in combination with other environmental impacts. Some of these models are briefly reviewed here.

2.2. Landuse Models

Work has been done on the conservation potential of different types of landuses, such as residential commercial and transportation (T.R.B., 702, 1976). A few studies have

addressed the question of landuse and transportation interaction, and the resulting energy consumption characteristi.. (Caroll et al 1977).

There are two primary purposes in including transporation energy in the operation of a landuse model. First, landuses generate trips which are in turn distributed among the different landuse activities. Variation in the location of these activities, therefore, can influence energy consumption levels. Development of a transportation energy optimising landuse model should contain explicit consideration of transportation system elements. The EMPIRIC (Hill, 1965) and the Penn-Jersey model (Siedman, 1969) have been based on such spatial interaction. This category of models has been seen as variations of the urban development model by Lowry (1969) and has been extremely useful in planning applications with revisions and improvements to its initial form (Garin 1966, Wilson, 1970). A model based on optimisation techniques, known as TOPAZ, was proposed by Brotchie (1969) which distribut.. trips among zones by means of a nonlinear gravity model.

The few studies which have attempted to incorporate energy measures into an urban model have all employed a Lowry-type model as a basis for their formulation. Of them, Cripps et. al. (1974) have proposed a model based on a trip distribution model, in which energy was introduced through

a mode and fuel specific rate of energy consumption for each zonal pair, which is multiplied by the entries of a calibrated O-D matrix. This allows variation only in destination and modal choice whereas origins and distributions are also variable for they are a function of the landuse activity.

A modified Lowry type model was used by Edwards and Schofer (1976) where total energy use of the landuse allocation is calculated using measures of average energy consumption per rider by each mode. The simulations show that as urban form is made more compact total transportation energy consumption is reduced. A third study using a Lowry type model has been completed by Carroll et. al. (1977) to simulate alternative development patterns in the Nassau Suffolk area of Long Island but the energy consumption was computed after the allocation of landuses. The model is, therefore, insensitive to the energy consumption of the transportation component.

With the exception of the Cripps et. al. (1974), the above models become concerned with energy only after urban development has been completely simulated; thereby assuming that energy plays no role in this development or in the trips associated with it.

The model proposed by Romanos et. al. (1980) is based on optimization but special efforts were made not to dispense with realistic urban location and travel behaviour in achieving an optimal distribution of landuses, while considering transportation energy as an integral part of the landuse allocation process. The energy consumption per person trip is determined by applying the energy intensity per person-mile to the shortest path between the origin and destination zones. Levinson (1981) identifies the transportation and transportation energy intensities of various landuses, assesses the effects of population density on energy consumption, and suggests measures to improve them. In rapidly growing areas the desirable actions are better landuse planning to encourage compact urban development, increase residential densities, balance jobs and people, expand transit ridership, encourage ridesharing and reduce per capita space requirements.

2.3. Environmental Impact Models

Some generalized models were proposed for the combined analysis of Environmental impacts like energy consumptions, congestion and vechicle emission. One such model is the TRANSYT 6C model proposed by Jonavis et.al.(1979). This model includes fuel consumption and vehicle emission impacts, spatial and modal demand responses. Eventhough it

is an arterial traffic management based model dealing with minimization ,a signal delay and utilisation of exclusive bus lanes, fuel consumption minimization was also one of the tested strategies. It was concluded that signal optimization to minimize vehicle delays resulted in moderate benefits in terms of fuel consumption and vehicle emissions savings. The test for the strategy of providing bus lanes also showed favourable results in terms of fuel and time savings.

Using fuel consumption as a single impact objective generally minimises fuel consumption for the study section, but stops are decreased considerably because the amount of fuel spent depends largely on the number of stops.

2.4 . Modal Shift Models

The aggregate distance travelled per traveller is a function of (a) spatial arrangement of desired destinations (b) the income level of the traveller and (c) the supply of travel opportunities in terms of the availability, speed, comfort and alternative modes (Transportation Research, 1982). Thus ,the mode and speed of transport contributes in important ways to the energy consumed per km. of travel.

A model developed by Horowitz (1977) estimates the aggregate characteristics of bus transit systems capable of carrying substantial fraction of person trip and by implication, automobile trips. The model was tested for Los

Angeles but is applicable to other cities also. The model is based on traffic districts and the demand for transit trips is developed from exogenously specified, transit modal-spite factor and district level trip tables. The trip tables give the number of personntrips per hour between each pair of districts, according to trip purpose and time of day. The mode-split factors give the fraction of trips of each purpose that will use transit if transit is provided between origin and destinations. The limitations of this model are that it is static and doesn't consider the travel cost criteria.

Investigation of modal shifts that result from energy-related transportation policies is relatively new and a few studies have emerged in this respect. Keck(1979), in a survey of three small urban areas in New York during and after the fuel shortage, showed that automobile users responded to the shortage by reducing speed, combining non-work trips with worktrips and to a lesser extent by carpooling.

Navine (1979) presented a utility based modal split as well as a fuel rationing model based on a trip purpose preferential model. He concluded from the first model that the percentage of modal shift is approximately one-fourth of the percentage of fuel price increase .

A model for intercity trips was developed by the State University of New York, Stony Brook, by considering the income, time, fare, occupancy and operating costs to evaluate the modal shift.

2.5. Bus Scheduling Models

Savings in fuel consumption is remotely related to the scheduling of buses. Since the number of bus trips to be made will be considerably reduced if they are used nearer to their capacity. This is possible by scheduling the buses so as to co-ordinate with the arrival times of the passengers. Several models have been developed in this respect to reduce the waiting time of the passengers and some of them are reviewed here.

Barnett et. al. (1974) formulated a model based on a single discrete approximation to the probability distribution of passenger arrival times at bus stops. Based on the model an optimal holding strategy was proposed to detain the buses at selected points so as to reduce the variance in headways. But the statistical parameters involved are large, consisting of correlation between successive vehicle arrival times at the control stop. The statistical estimation of these parameters is difficult because of the small sample sizes available and the unreliability of the estimates of co-variance.

Abkowitz et. al. (1978) has proposed a control strategy based on similar lines to hold the buses at strategic points along a route to regularize the headways between successive vehicles. i.e. a vehicle that arrives too closely at the control stop is deliberately delayed to make the headways nearly equal to the scheduled headway. But the major cost of such a policy is borne by the passengers who are already on the vehicle.

Turnquist (1979) also suggested a similar headway control strategy to improve the reliability of transit service. Adherence to the schedule is important to the users to reduce the wait time, enable better transfers and increase the certainity of arrivaltime at the destinations. To the operators unreliability results in ineffective utilization of the equipment and personnèland reflects itself in cost and reduced productivity of the systems operation.

Bisbee et. al. (1969) proposed an objective function consisting of the sum of operating cost for vehicles plus a cost for delay of passengers and showed the calculation of dispatch times of vehicles so as to minimize the total cost.

3. COLLECTION OF DATA

3.1. General

The design of a proposed program requires an estimate of likely impacts on the environment in which it is to be implemented. However the level of accuracy required in such an evaluation must be appropriate to the cost of the action and the scale of the expected impacts. The impact prediction process must replicate as closely as possible, the actual impact of the strategy on the systems performance and travel behaviour . This is possible through collection of data for the existing system and projecting it, to study the modified system.

In thiscase, the fuel consumption for a medium-sized city was analysed for the Home-to-workplace trips the destination being the Industrial Zone. Since the consumption of fuel is a function of the number of trips made to this Industrial area, it is necessary that the magnitude of this movement be known to evaluate the former for further studies.

3.1.1 Data Requirement

To estimate the number of trips originating from the entire city and destined for the Industrial area, a sample survey has to be conducted for the current movement. This movement is then projected to determine the total number of trips made by the entire population. This is done on the

basis of the volume recorded on the roads connecting the Industrial area with the city. Since the cost analysis is to be performed, the Operating costs of the existing Bus System are also to be known.

3.2. Choice of the City

It is generally observed that the Public Transit System in a medium-sized city is incapable of meeting the peak hour demand. This is due to the fact that the Traffic is mixed in nature, which is responsible for lowering its average speed especially in the absence of separate lanes for different types of vehicles. The existing landuse pattern also prevents improvement of the roads. Moreover, during the peak hour a large number of trips are made to the Industrial areas on specific roads by privately owned vehicles.

In the recent past the city development authorities have taken steps in controlling the growth of Industries to allow a healthy and planned development. The general trend has been to establish Industrial Estates under the guidance of the respective state Industrial Development Corporations. Nagpur city closely follows such a landuse pattern and also represents a major cross-section of such cities in our country and hence has been chosen for this case study.

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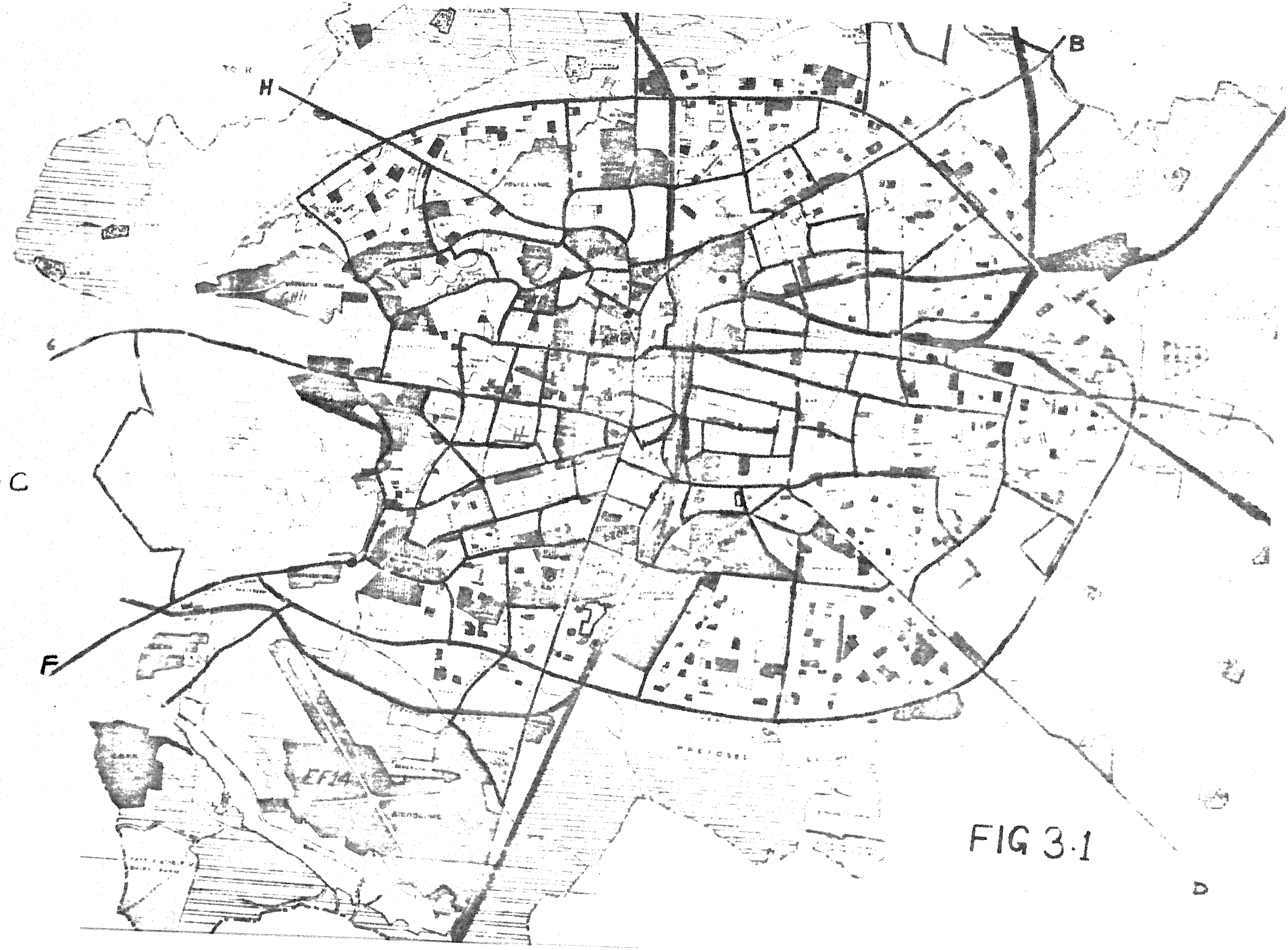

FIG 3.1

3.2.1. Brief Account of the City

Nagpur city has a population of 1.2 million and is located in the North-Eastern region of the Maharashtra state and also in the heart of the country. The city is well connected by roads, railways and domestic airlines. It forms the junction for the National highways no. 6 and 7 and also for the trunk railway routes between Delhi and Madras, and Bombay and Calcutta. It is connected by air with Bombay, Calcutta, Delhi and Hyderabad. After the saturation of the Industrial areas in Bombay, the State government had decided to decentralise their growth by offering incentives for setting up industries at Pune, Nagpur and Nasik. This led to the spurt in the Industrial activities in these cities.

In Nagpur, 18 sq. kms of land was earmarked for this purpose and developed as the Hingna Industrial Estate. This Estate is located in the west, on the outskirts of the city and is about 10 kms from the Central Bussiness District (CBD). The layout of the city is shown in fig. 3.1. This location was chosen for the estate to avoid pollution in the city and also because of its proximity from the 300 MW Koradi Thermal Power Plant and Pench Water Canal Project which is expected to be completed by 1983. Over 300 Industries are located in thisestate ranging from Automobile Manufacturing, Pharmaceutical, small scale steel plants to their ancillaries. The estate is connected by Highways to the city one leading

to Amravati city and the other to Hingna. Due the recent spurt in the Industrial activity in this area the traffic flow has increased considerably on these roads. The city Development Authorities have planned the layout for a ring road meant to divert the heavy traffic originating from the Industrial area away from the city. This project is expected to be completed by 1990.

The city has lacked proper planning in the CBD. The Commercial centres and the Government offices are located on the North of the CBD. The North-Eastern region is the older part of the city and ishighly congested. The western zone is nearly residential and is better planned. The roads connecting the Eas tern and the Western regions of the city are constricted by the CBD thus forming a bottleneck butthe traffic from the northern and southern regions bypasses the CBD. The Railway lines cut across the heart of the city and intersect the vital roads at several points.

The Industrial workers travel to the Industrial sector from various parts of the city, the average triplength being 8.0 Kms. Some major Industries provide private transport from selected points in the city but the number of such Industries is quite less. The present Bus service plies upto Hingna but not into the Industrial Estate. The Industries being widely spaced, the walking time is pretty high. These conditions have led to the dependence and increased use of

private vehicles especially light Two-Wheelers like mopeds. A worker on the average travels for 20 to 35 minutes to reach his workplace from his home. Since most of the Industries have located their administrative offices adjacent to their Factories the tripmakers consist of Office-goers also thus increasing the total number of trips made during the peak hours each day. Thus it is observed that the city closely represents a case for which the strategy has been proposed in this study.

3.3. Mode of Data Collection

Data collection always forms a major component of any Transportation project, since the demand is projected on its basis. At the same time it turns out to be the most expensive and time consuming part of the project. Hence it is necessary that the sample size for its collection be judiciously decided. A survey is then conducted for this sample size to estimate the actual demand.

3.3.1. Design of Questionnaire

Since the detailed information was to be collected regarding the trips made by the workers, it was not possible to conduct on-the-spot interviews. Hence it was decided to collect the required information through Questionnaires. The Questionnaire was designed so as to enable the subjects fill in the desired information quickly and correctly.

The required information was collected under the following items :

(i) Type of the Vehicle used.

(ii) Approximate distance between office/factory and and Residence.

(iii) Location of residence.

(iv) Location of Factory.

(v) Approximate time taken by own vehicle for work-trips.

(vi) Number of work-trips made each day.

(vii) Average Fuel consumption per day.

(viii) Frequency of usage of private vehicles.

(ix) Details regardingtravel by alternate modes including Public Transit.

A format of the Questionnaire distributed is shown in Appendix A.

3.3.2. Volume Studies

The Traffic volume study was conducted for the road connecting the Industrial area with the rest of the city. The volume was recorded for two peak hours on road 'F' shown in fig. 3.1. The recording periods were from 9:00 AM to 10:00 AM and 5 : 00 PM to 6:00 PM. The volume of two-wheelers (scooters, mopeds and motorcycles) and Four-Wheelers (cars) was recorded during this period. The recorded volumes

were 606 vehicles for two wheelers and 167 vehicles for four-wheelers during the two peak hours.

3.3.3. Origin and Destination Studies

The sample size for thissurvey was fixed in the following manner.

Based on the studies in the past, the observed volume for the two hour peak period was assumed to be 20% of the Average Daily Traffic (ADT) from which the ADT of Two-Wheelers and Four-Wheelers was found to be 3030 and 830 vehicles respectively. Thus the total flow is nearly 3900 vehicles during this period. The sample size for estimating the trip distribution was taken as 10% of the total volume which is also based on the past studies. (Creighton, 1972).

An Origin and Destination study was then conducted for a sample size of 500, by distributing the Questionnaires to the workers making trips to the Industrial area by cars, scooters, motorcycles and mopeds.

3.3.4. Bus Operating Costs

Since the proposed study was aimed at analysing the savings resulting from the modal shift of private vehicle owners to public transit, it was necessary to obtain information regarding the Operating costs of the present Bus system. This information was provided by the

TABLE 3.1. OPERATING COST PER Km. FOR BUSES IN NAGPUR.

HEADS	Rs. P.
(1) Salary and allowances	0.84
(2) Fuel and lubricants	0.42
(3) Repairs and spare parts	0.38
(4) Overheads	0.29
(5) Depreciation	0.33
(6) Head Quarter Charges	0.29
Total Cost	2.55

Maharashtra State Road Transport Corporation and the breakup of the total operating cost is shown in Table 3.1 and is bas on the figures available for 1979.

Thus the data collected for the city of Nagpur furnished information regarding the origin and Destination of work-trips, their triplength, traveltime and the monthly fuel consumption.

4. THE PLANNING AND DESIGN OF BUS TRANSIT SYSTEM

4.1. General

The development of public Transportation systems in recent years have been based on reducing the adverse effects of overreliance on privately owned vehicles, one of the major effects being the excessive consumption of energy. Even though the provision of an efficient public transit system seems to be a potential strategy to conserve energy, reduce congestion and avoid further construction of new roads and facilities, it is essential that the mature and scale of environmental impacts be studied for good and ill. Such impacts occur when a new transit system or a component is added to an existing system, which should be perceived and evaluated for the given strategy. Economic analysis has often been an important component in evaluating the feasibility of a project as it is an effective way to compute and compare the costs and benefits. Here the study has been limited to evaluate the economic feasibility of an improved bus system planned with the goal as reduction in energy consumption.

4.2. Presentation of Data

Prior to the processing of data, it is necessary that it should be screened for ambiguous responses and irrelevant information, followed by systematic tabulation

under desirable categories. This is done so as to ensure that the data collected is realistic and easier to analyse.

In the data collection for the city of Nagpur, 500 responses were received which contained information regarding the origin and destination of trips, triplength, traveltime and the monthly fuel consumption. Each response was verified for the entries of origin and destination of each trip, travel time, triplength and monthly fuel consumption. Since the origin and destination of each trip was known, any ambiguous entry for trip length was corrected. Similarly, unrealistic figures in travel time and fuel consumption entries were replaced by extrapolation. Of the 500 responses received, 50 had to be rejected on the grounds of irrelevant information. Since the survey was conducted for scooters, mopeds, motorcycles and cars, the next step was to categorize the data under two-wheelers and four-wheelers. Out of the 450 corrected responses 407 were categorized as two-wheelers and the rest as four-wheelers. At this stage, the information about each trip maker regarding his origin and destination, triplength, traveltime and monthly fuel consumption was available.

Based on this information, the travel speed of each tripmaker and the distance covered per litre of fuel consumed was computed for each trip maker. Twenty six

TABLE 4.1. CUMULATIVE FREQUENCY DISTRIBUTION FOR TRIPLENGTH OF TWO-WHEELERS AND FOUR-WHEELERS.

S.NO.	CLASS INTERVAL	FREQUENCY	CUM.FREQ.	REL.CUM.FREQ.
FOR TWO-WHEELERS-				
1	0.00- 0.99	0	0	0.00
2	1.00- 1.99	0	0	0.00
3	2.00- 2.99	8	8	1.96
4	3.00- 3.99	13	21	5.15
5	4.00- 4.99	42	63	15.47
6	5.00- 5.99	40	103	25.30
7	6.00- 6.99	52	155	38.08
8	7.00- 7.99	35	190	46.68
9	8.00- 8.99	36	226	55.52
10	9.00- 9.99	13	239	58.72
11	10.00-10.99	37	276	67.81
12	11.00-11.99	7	283	69.53
13	12.00-12.99	32	315	77.39
14	13.00-13.99	5	320	78.62
15	14.00-14.99	46	366	89.92
16	15.00-15.99	10	376	92.38
17	16.00-16.99	31	407	100.00
FOR FOUR-WHEELERS-				
1	0.00- 0.99	0	0	0.00
2	1.00- 1.99	0	0	0.00
3	2.00- 2.99	0	0	0.00
4	3.00- 3.99	0	0	0.00
5	4.00- 4.99	7	7	16.27
6	5.00- 5.99	11	18	41.86
7	6.00- 6.99	1	19	44.18
8	7.00- 7.99	4	23	53.48
9	8.00- 8.99	1	24	55.81
10	9.00- 9.99	2	26	60.46
11	10.00-10.99	10	36	83.72
12	11.00-11.99	1	37	86.04
13	12.00-12.99	1	38	88.37
14	13.00-13.99	0	38	88.37
15	14.00-14.99	0	38	88.37
16	15.00-15.99	0	38	88.37
17	16.00-16.99	0	38	88.37
18	17.00-17.99	0	38	88.37
19	18.00-18.99	5	43	100.00

FOR TWO-WHEELERS: SAMPLE SIZE=407. MEAN= 8.83
FOR FOUR-WHEELERS: SAMPLE SIZE= 43. MEAN= 8.37

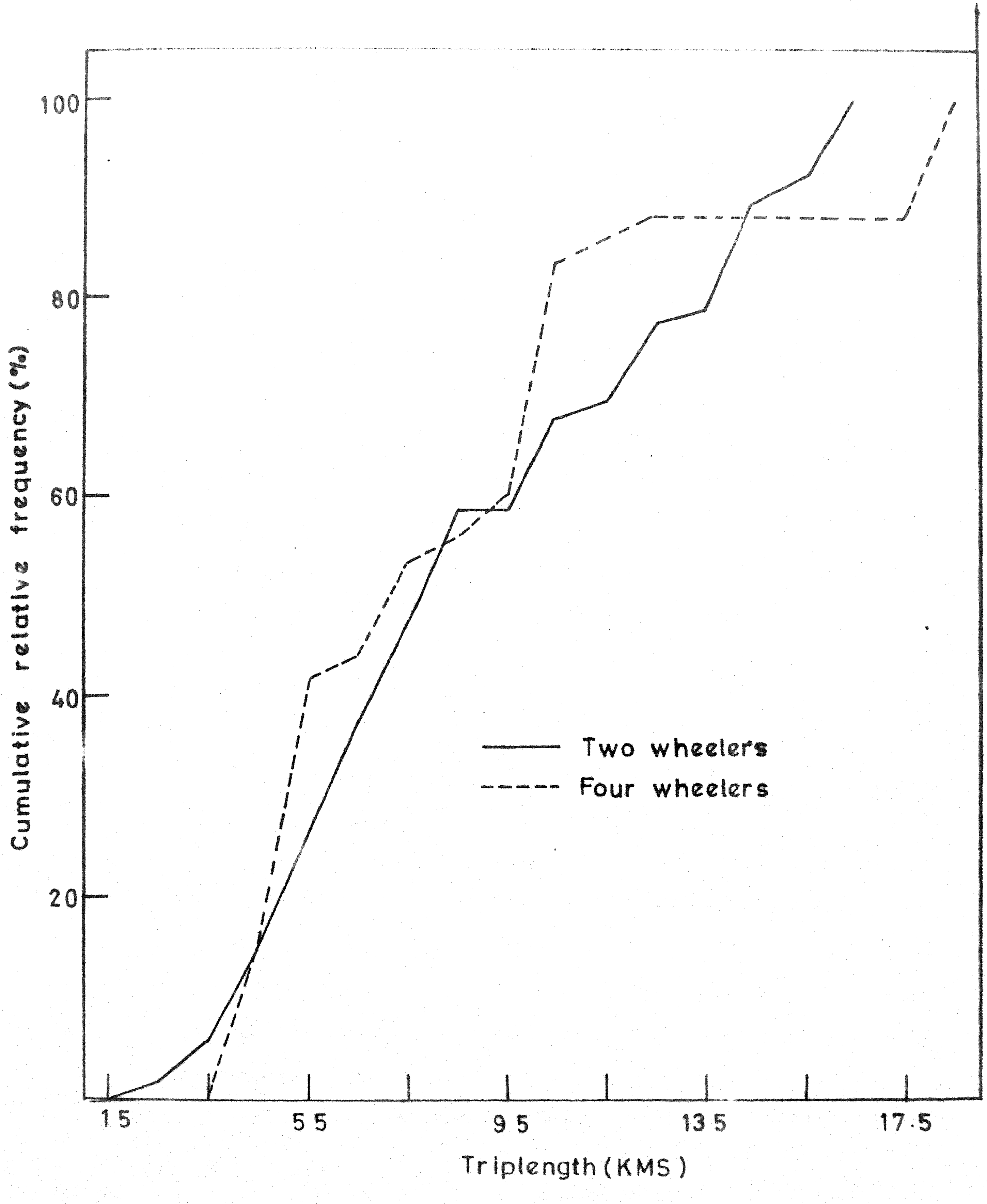

FIG. 4.1 CUMULATIVE RELATIVE FREQUENCY POLYGON FOR TRIPLENGTH

working days were considered for the home-to-workplace trips made for the computation of distance covered per litre of fuel henceforth known as Kilometerage.

4.3 Characteristics of data

The raw data can be better understood if categorized in suitable classes and the frequency be determined. The trend followed by each item and the various statistical measures viz. mean, mode and percentiles can also be determined. For each item the relative cumulative frequency distribution was determined for two-wheelers and four - wheelers seperately and plotted against the class intervals for triplength, traveltime, monthly fuel consumption, travel speed and distance covered per litre of fuel.

4.3.1. Statistical Measures

(i) Triplength :

The frequency and the relative cumulative frequency for the home-to-workplace triplength is shown in Table 4.1 and the corresponding frequency distribution is shown in Fig. 4.1. The table shows that for two-wheelers the trip length varies from 2 to 17 Kms. and the maximum number of trips made are of triplength between 6 to 7 Kms., the mean triplength being 8.84 Kms. The distribution shows that for two-wheelers 25% of the trips are less than 5.5. Kms. in length, 50% less than 7.8 Kms. and nearly 80% are less

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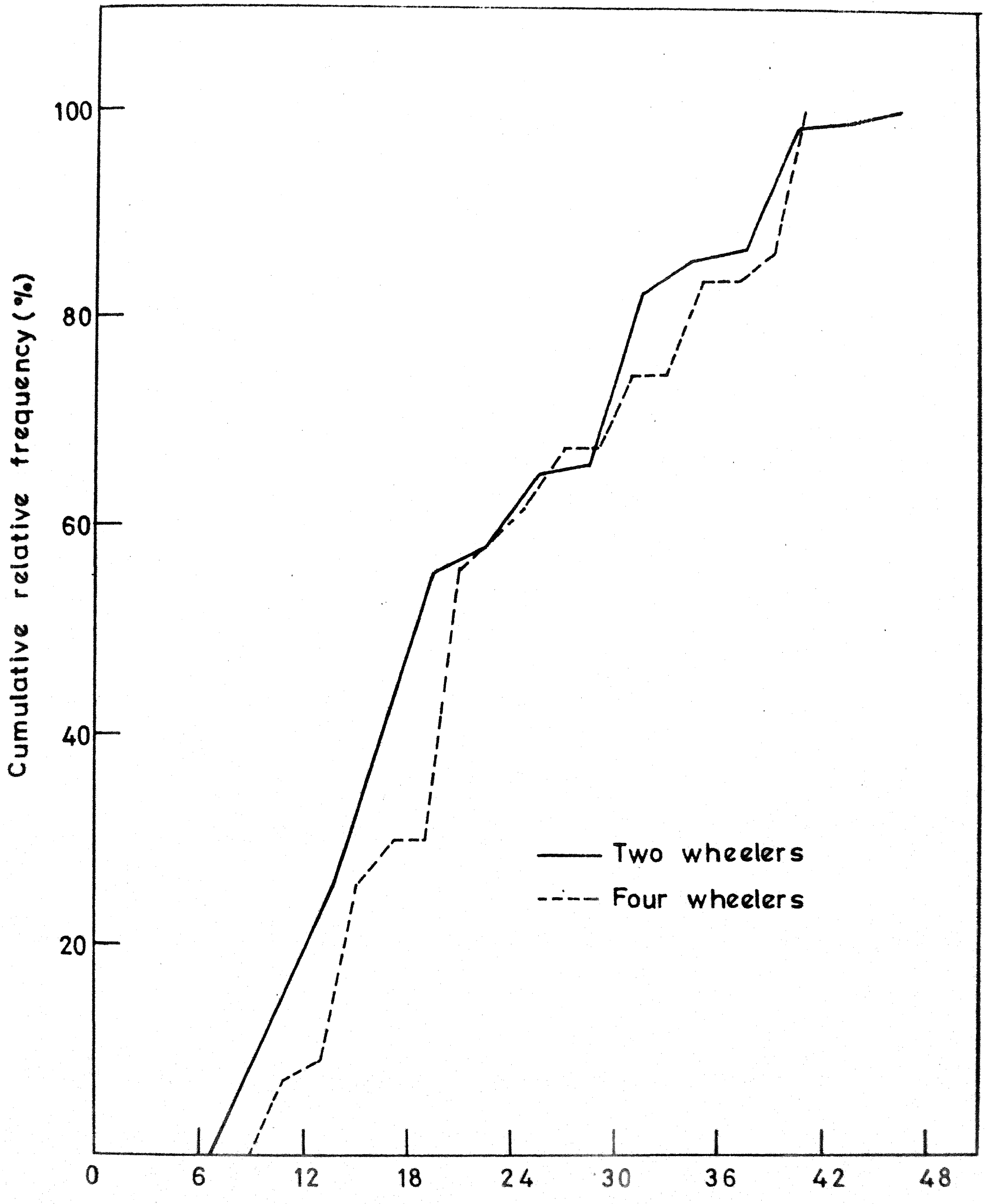

FIG 4.2 CUMULATIVE RELATIVE FREQUENCY POLYGON FOR TRAVEL TIME

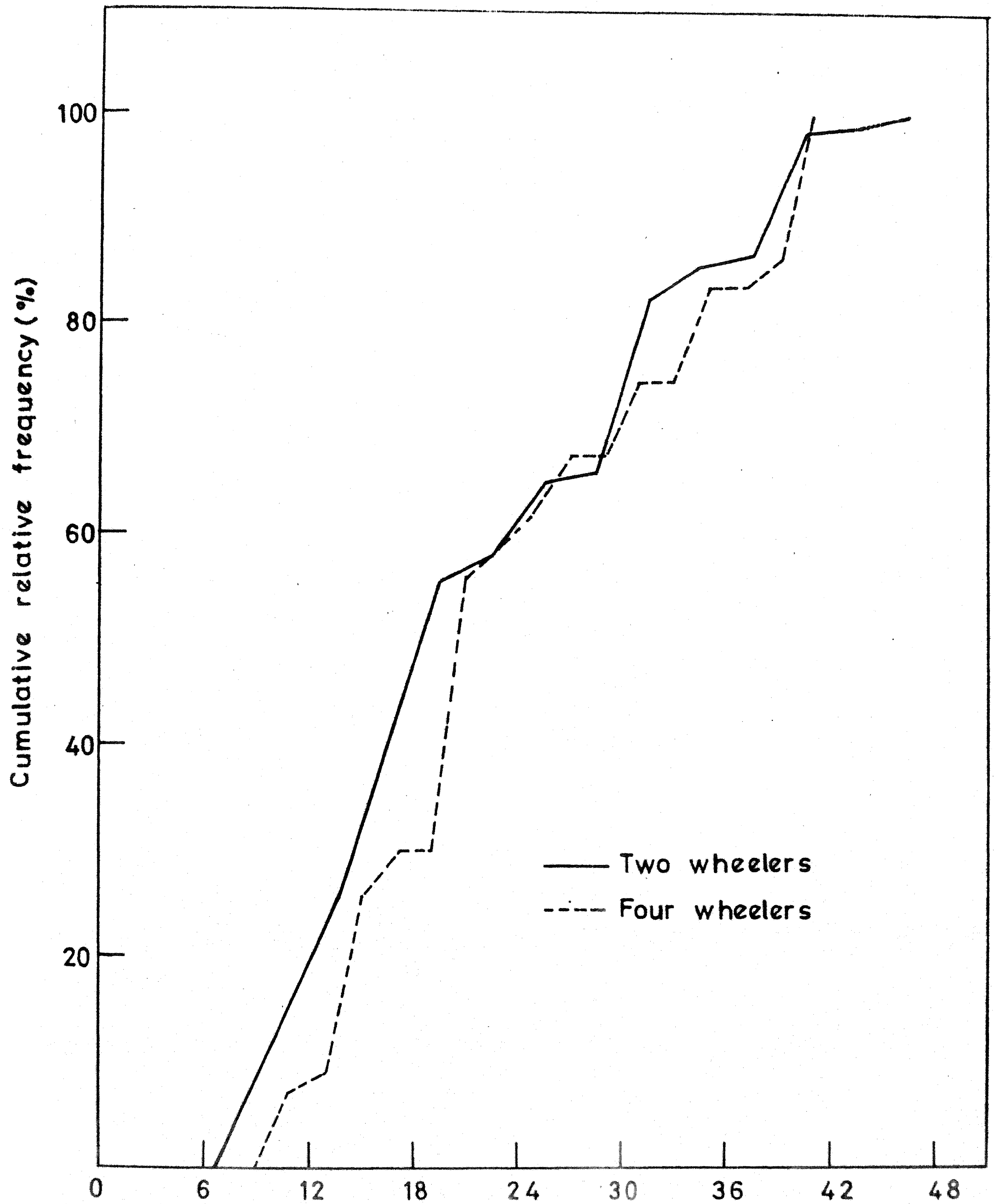

FIG 4.2 CUMULATIVE RELATIVE FREQUENCY POLYGON FOR TRAVEL TIME

TABLE 4.2. CUMULATIVE FREQUENCY DISTRIBUTION FOR TRAVEL TIME OF TWO-WHEELERS AND FOUR-WHEELERS.

S.NO.	CLASS INTERVAL	FREQUENCY	CUM.FREQ.	REL.CUM.FREQ.
FOR TWO-WHEELERS-				
1	0.00- 2.99	0	0	0.00
2	3.00- 5.99	7	7	1.71
3	6.00- 8.99	8	15	3.68
4	9.00-11.99	41	56	13.75
5	12.00-14.99	48	104	25.55
6	15.00-17.99	66	170	41.76
7	18.00-20.99	56	226	55.52
8	21.00-23.99	10	236	57.98
9	24.00-26.99	29	265	65.11
10	27.00-29.99	3	268	65.84
11	30.00-32.99	66	334	82.06
12	33.00-35.99	14	348	85.50
13	36.00-38.99	4	352	86.48
14	39.00-41.99	49	401	98.52
15	42.00-44.99	2	403	99.01
16	45.00-47.99	4	407	100.00
FOR FOUR-WHEELERS-				
1	0.00- 1.99	0	0	0.00
2	2.00- 3.99	0	0	0.00
3	4.00- 5.99	0	0	0.00
4	6.00- 7.99	0	0	0.00
5	8.00- 9.99	0	0	0.00
6	10.00-11.99	3	3	6.97
7	12.00-13.99	1	4	9.30
8	14.00-15.99	7	11	25.58
9	16.00-17.99	2	13	30.23
10	18.00-19.99	0	13	30.23
11	20.00-21.99	11	24	55.81
12	22.00-23.99	1	25	58.13
13	24.00-25.99	2	27	62.79
14	26.00-27.99	2	29	67.44
15	28.00-29.99	0	29	67.44
16	30.00-31.99	3	32	74.41
17	32.00-33.99	0	32	74.41
18	34.00-35.99	4	36	83.72
19	36.00-37.99	0	36	83.72
20	38.00-39.99	1	37	86.04
21	40.00-41.99	6	43	100.00

FOR TWO-WHEELERS: SAMPLE SIZE=407. MEAN= 22.38
FOR FOUR-WHEELERS: SAMPLE SIZE= 43. MEAN= 24.05

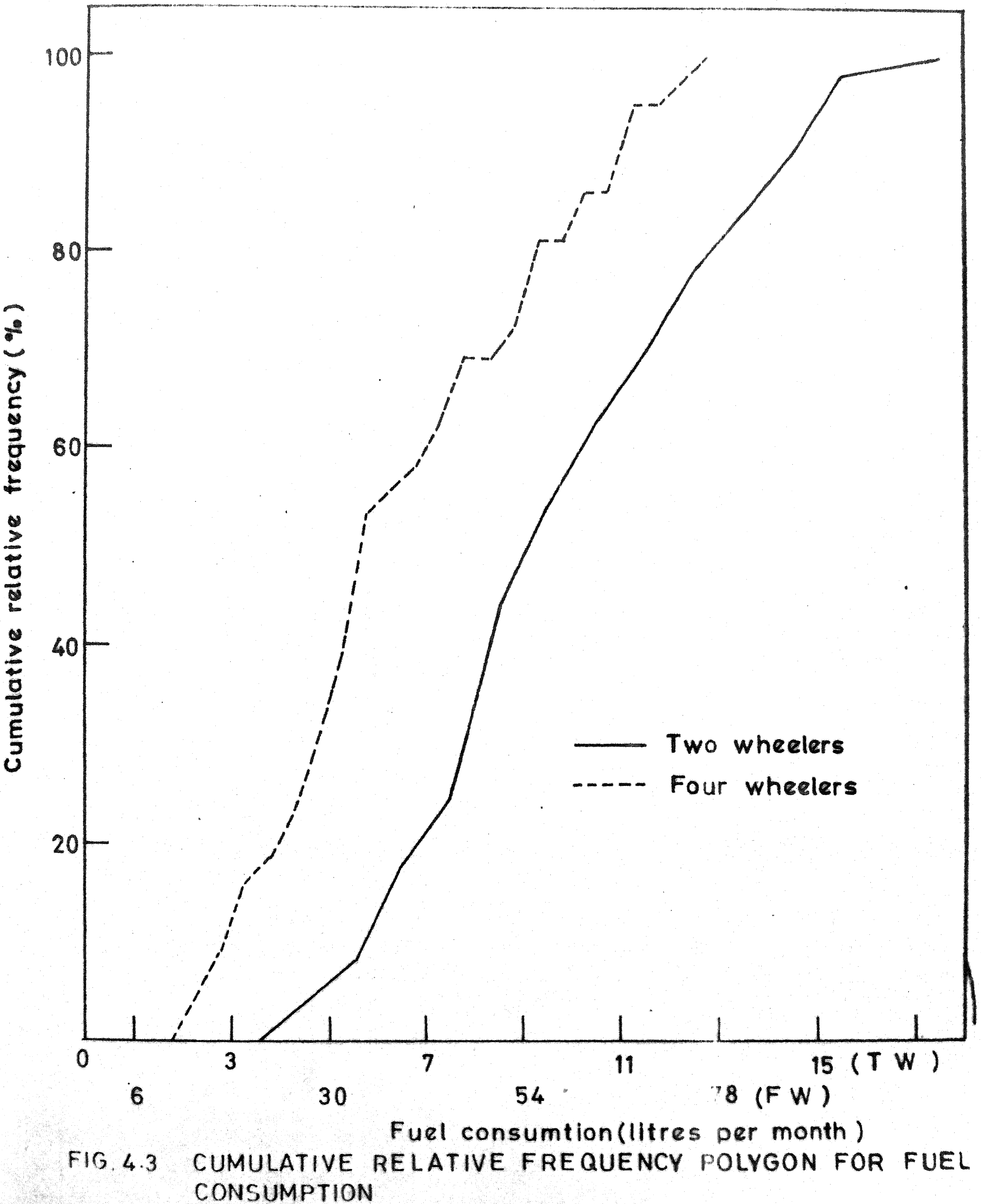

FIG. 4.3 CUMULATIVE RELATIVE FREQUENCY POLYGON FOR FUEL CONSUMPTION

TABLE 4.3. CUMULATIVE FREQUENCY DISTRIBUTION FOR MONTHLY FUEL CONSUMPTION OF TWO-WHEELERS AND FOUR-WHEELERS.

S.NO.	CLASS INTERVAL	FREQUENCY	CUM.FREQ.	REL.CUM.FREQ.
FOR TWO-WHEELERS-				
1	0.00- 0.99	0	0	0.00
2	1.00- 1.99	0	0	0.00
3	2.00- 2.99	0	0	0.00
4	3.00- 3.99	0	0	0.00
5	4.00- 4.99	16	16	3.93
6	5.00- 5.99	18	34	8.35
7	6.00- 6.99	39	73	17.93
8	7.00- 7.99	27	100	24.57
9	8.00- 8.99	79	179	43.98
10	9.00- 9.99	44	223	54.79
11	10.00-10.99	33	256	62.89
12	11.00-11.99	27	283	69.53
13	12.00-12.99	37	320	78.62
14	13.00-13.99	22	342	84.02
15	14.00-14.99	26	368	90.41
16	15.00-15.99	34	402	98.77
17	16.00-16.99	0	402	98.77
18	17.00-17.99	5	407	100.00
FOR FOUR-WHEELERS-				
1	0.00- 2.99	0	0	0.00
2	3.00- 5.99	0	0	0.00
3	6.00- 8.99	0	0	0.00
4	9.00-11.99	0	0	0.00
5	12.00-14.99	2	2	4.65
6	15.00-17.99	2	4	9.30
7	18.00-20.99	3	7	16.27
8	21.00-23.99	1	8	18.60
9	24.00-26.99	2	10	23.25
10	27.00-29.99	3	13	30.23
11	30.00-32.99	4	17	39.53
12	33.00-35.99	6	23	53.48
13	36.00-38.99	1	24	55.81
14	39.00-41.99	1	25	58.13
15	42.00-44.99	2	27	62.79
16	45.00-47.99	3	30	69.76
17	48.00-50.99	0	30	69.76
18	51.00-53.99	1	31	72.09
19	54.00-56.99	4	35	81.39
20	57.00-59.99	0	35	81.39
21	60.00-62.99	2	37	86.04
22	63.00-65.99	0	37	86.04
23	66.00-68.99	4	41	95.34
24	69.00-71.99	0	41	95.34
25	72.00-74.99	1	42	97.67
26	75.00-77.99	1	43	100.00

FOR TWO-WHEELERS: SAMPLE SIZE=407. MEAN= 9.75
FOR FOUR-WHEELERS: SAMPLE SIZE= 43. MEAN= 39.58

than 13.5 Kms.

For cars the maximum triplength is 19 Kms.and the minimum triplength made is 4 Kms., the average being 8.38 Kms. From the cumulative distribution curve it can be seen that 25% of the persons travel less than 4.8 Kms. 50% less than 7 Kms. and 80% less than 10.3 Kms.

(ii) Travel - Time :

The distribution of the time taken for the home-to-workplace trips is shown in fig. 4.2 and the corresponding frequencies are shown in Table 4.2.

It is observed that for two-wheelers the worktrip travel time ranges between 3 to 4.8 minutes, the maximum number of trips taking 15 to 18 minutes. 55% of the trips take less than 19.5 minutes and 80% take less than 31 minutes.

For owners of cars, the trip time ranges between 10 to 42 minutes, the maximum number of trips taking 20 to 22 minutes. 50% of the trips take less than 21 minutes and 80% take less than 34 minutes.

(iii) Monthly Fuel Consumption :

The cumulative distribution for the monthly fuel consumption of two-wheelers and four-wheelers is shown in fig. 4.3 and the corresponding frequencies are shown in Table 4.3.

TABLE 4.4. CUMULATIVE FREQUENCY DISTRIBUTION FOR SPEED OF TWO-WHEELERS AND FOUR-WHEELERS.

S.NO.	CLASS INTERVAL	FREQUENCY	CUM.FREQ.	REL.CUM.FREQ.
FOR TWO-WHEELERS-				
1	0.00- 1.99	0	0	0.00
2	2.00- 3.99	0	0	0.00
3	4.00- 5.99	0	0	0.00
4	6.00- 7.99	0	0	0.00
5	8.00- 9.99	0	0	0.00
6	10.00-11.99	0	0	0.00
7	12.00-13.99	0	0	0.00
8	14.00-15.99	3	3	0.73
9	16.00-17.99	8	11	2.70
10	18.00-19.99	31	42	10.31
11	20.00-21.99	30	72	17.69
12	22.00-23.99	1	73	17.93
13	24.00-25.99	93	166	40.78
14	26.00-27.99	27	193	47.42
15	28.00-29.99	54	247	60.68
16	30.00-31.99	57	304	74.69
17	32.00-33.99	42	346	85.01
18	34.00-35.99	9	355	87.22
19	36.00-37.99	41	396	97.29
20	38.00-39.99	11	407	100.00
FOR FOUR-WHEELERS-				
1	0.00- 1.99	0	0	0.00
2	2.00- 3.99	0	0	0.00
3	4.00- 5.99	0	0	0.00
4	6.00- 7.99	0	0	0.00
5	8.00- 9.99	0	0	0.00
6	10.00-11.99	0	0	0.00
7	12.00-13.99	0	0	0.00
8	14.00-15.99	1	1	2.32
9	16.00-17.99	1	2	4.65
10	18.00-19.99	2	4	9.30
11	20.00-21.99	1	5	11.62
12	22.00-23.99	0	5	11.62
13	24.00-25.99	8	13	30.23
14	26.00-27.99	7	20	46.51
15	28.00-29.99	9	29	67.44
16	30.00-31.99	12	41	95.34
17	32.00-33.99	1	42	97.67
18	34.00-35.99	1	43	100.00

FOR TWO-WHEELERS: SAMPLE SIZE=407. MEAN= 27.50
FOR FOUR-WHEELERS: SAMPLE SIZE= 43. MEAN= 26.89

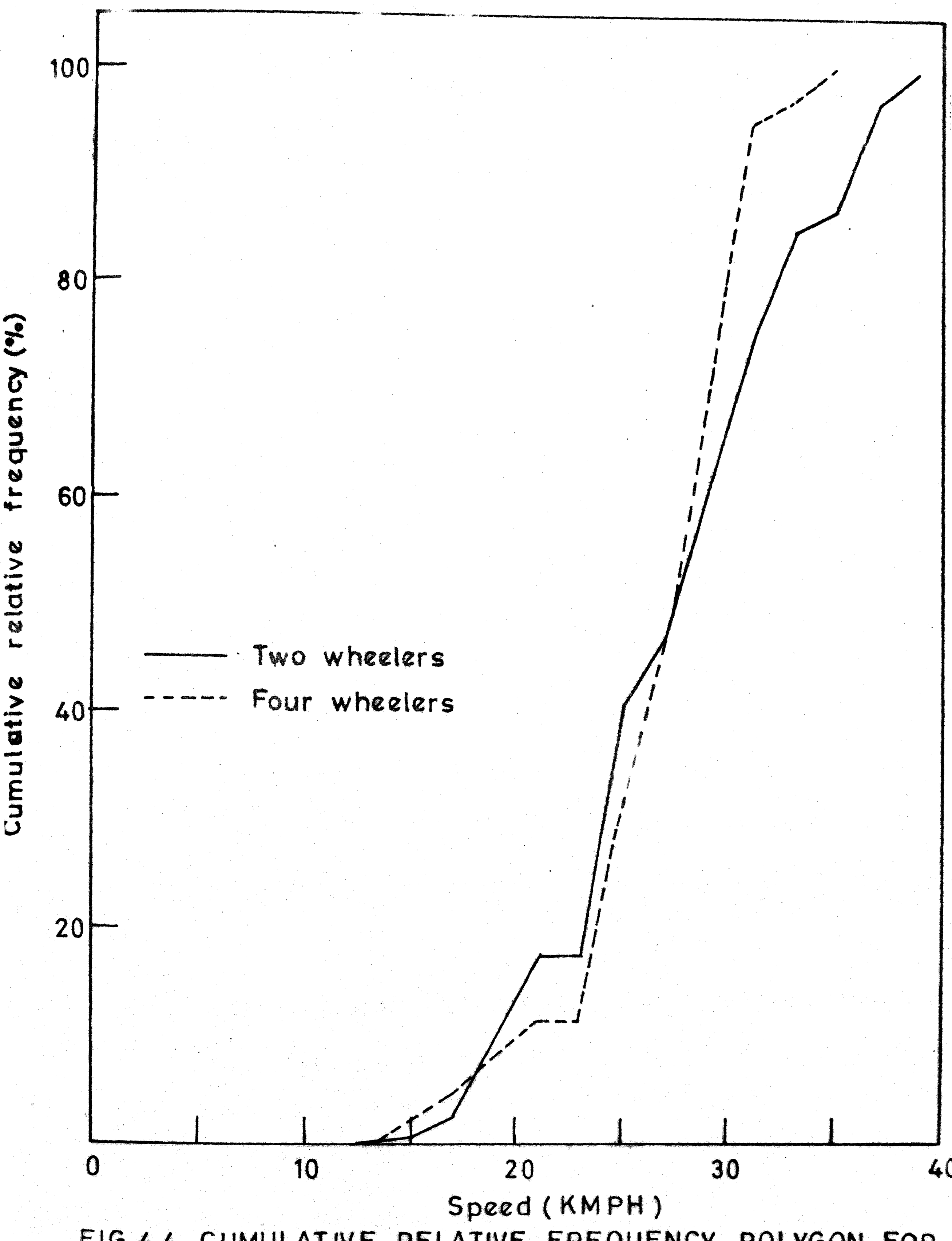

FIG.4 4 CUMULATIVE RELATIVE FREQUENCY POLYGON FOR SPEED

For two -wheelers the monthly fuel consumption ranges between 4 to 18 litres per month, but the maximum number of persons spend 8 to 9 litres per month. 30% of the workers spend less than 7.8 litres per month, 55% spend less than 9.6 litres and 90% spend less than 14.5 litres per month.

For cars the consumption range is between 12 to 78 litres per month. The upper bound of the range is high as some subjects made more than two trips a day but the maximum number of car-owners consume fuel between 33 to 36 litres per month It is noticed from the distribution that 40% of the car-owners consumed less than 32 litres per month, nearly 70% less than 51 litres and 90% less than 66 litres per month.

(iv) Travel speed :

The travel speed variation of two-wheelers and four-wheelers is shown in fig. 4.4. From the frequency table 4.4, it is found that the maximum number of persons travel at speeds ranging between 24 to 26 Kmph. Since this speed is computed from the total travel time for the worktrip and the distance between the origin and the destination, it accounts for the delay caused by the intersections, signals and the traffic on the road. The maximum travel speed attained by two-wheelers was 40 Kmph. Such speed is attained by tripmakers originating from the

TABLE 4.5. CUMULATIVE FREQUENCY DISTRIBUTION FOR DISTANCE COVERED/LITRE OF TWO-WHEELERS AND FOUR-WHEELERS.

S.NO.	CLASS INTERVAL	FREQUENCY	CUM.FREQ.	REL.CUM.FREQ.
FOR TWO-WHEELERS-				
1	0.00- 2.99	1	1	0.24
2	3.00- 5.99	0	1	0.24
3	6.00- 8.99	0	1	0.24
4	9.00-11.99	0	1	0.24
5	12.00-14.99	0	1	0.24
6	15.00-17.99	0	1	0.24
7	18.00-20.99	7	8	1.96
8	21.00-23.99	16	24	5.89
9	24.00-26.99	38	62	15.23
10	27.00-29.99	32	94	23.09
11	30.00-32.99	111	205	50.36
12	33.00-35.99	62	267	65.60
13	36.00-38.99	67	334	82.06
14	39.00-41.99	15	349	85.74
15	42.00-44.99	20	369	90.66
16	45.00-47.99	20	389	95.57
17	48.00-50.99	18	407	100.00
FOR FOUR-WHEELERS-				
1	0.00- 0.99	0	0	0.00
2	1.00- 1.99	0	0	0.00
3	2.00- 2.99	0	0	0.00
4	3.00- 3.99	0	0	0.00
5	4.00- 4.99	0	0	0.00
6	5.00- 5.99	0	0	0.00
7	6.00- 6.99	1	1	2.32
8	7.00- 7.99	5	6	13.95
9	8.00- 8.99	3	9	20.93
10	9.00- 9.99	7	16	37.20
11	10.00-10.99	15	31	72.09
12	11.00-11.99	6	37	86.04
13	12.00-12.99	4	41	95.34
14	13.00-13.99	0	41	95.34
15	14.00-14.99	0	41	95.34
16	15.00-15.99	2	43	100.00

FOR TWO-WHEELERS: SAMPLE SIZE=407. MEAN= 33.40
FOR FOUR-WHEELERS: SAMPLE SIZE= 43. MEAN= 10.16

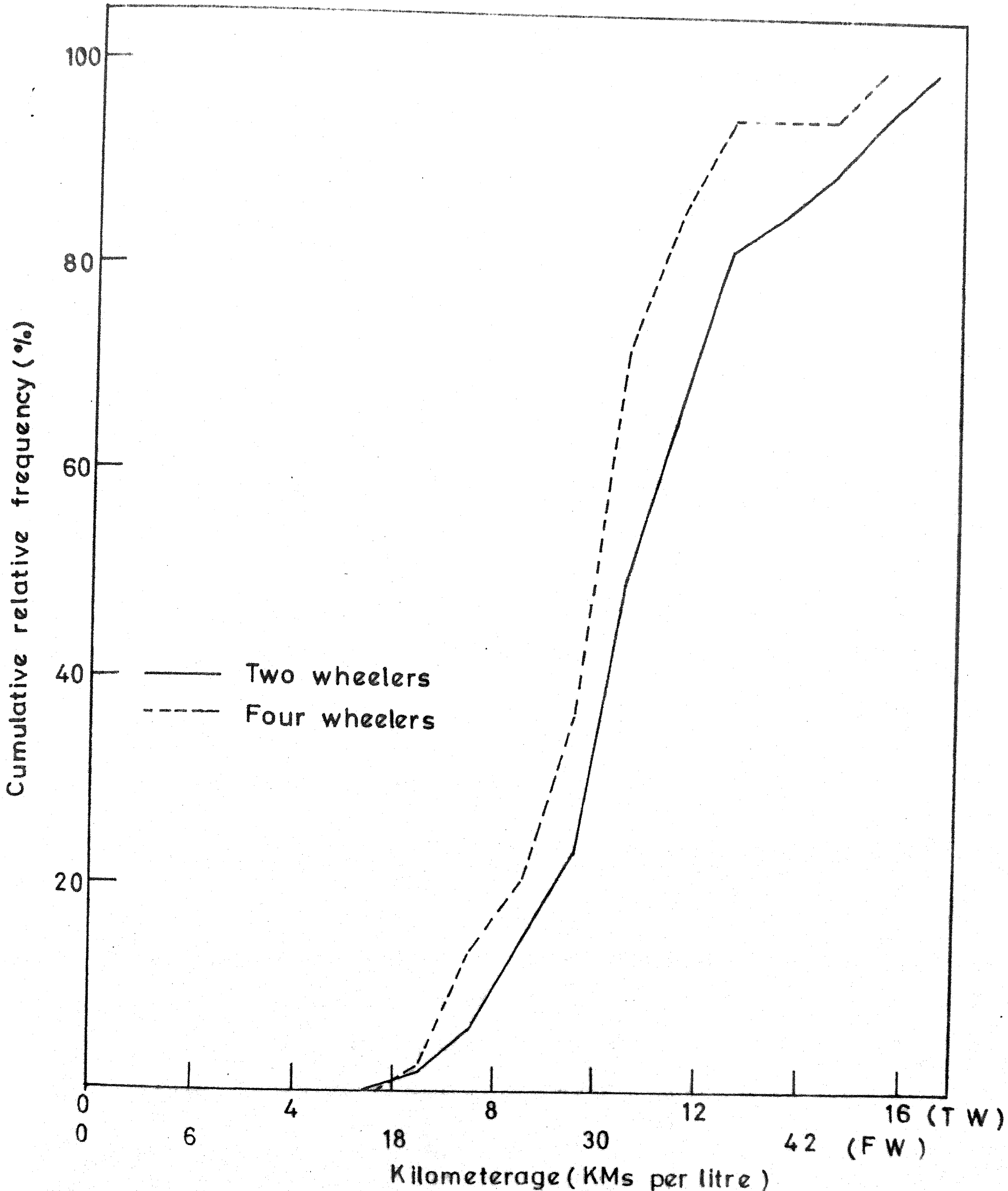

FIG. 4.5 CUMULATIVE RELATIVE FREQUENCY POLYGON FOR KILOMETERAGE

eastern region of the city as this area is relatively better planned and the road connecting the industrial zone has a lower volume of traffic beyond the outskirts of the city. The percentiles show that 40% of the trips made by two-wheelers are at an average speed less than 25 Kmph and 85% are less than 32 Kmph.

The distribution for cars shows a similar trend but more person travel at a speed between 30 to 32 Kmph. The percentiles show that nearly 45% of the cars travel at a speed less than 27 Kmph which is same as that of two-wheelers and 90% of car owners travel at less than 31 Kmph.

(v) Average Fuel Consumption (Kilometerage) :

The average fuel kilometerage or the distance covered per litre of fuel consumed is computed on the basis of the data available for the triplength and the monthly fuel consumption. The distribution is shown in Fig. 4.5 for two-wheelers and 4-wheelers and the frequencies is Table 4.5. For two-wheelers the average fuel consumption ranges between 18 to 51 Km/litre. During the survey various types of vehicles viz. scooters, mopeds and motorcycles were considered in this category. Mopeds lie on the upper bound of this range while motorcycles are at the lower bound. The scooters are some where midway between the range. Hence it is found that the maximum number of tripmakers travel by scooters

and the average fuel consumption ranges between 30 to 33 Kms/litre. The distribution show that nearly 25% of the vehicles cover 28.5 Kms/litre and 85% cover less than 40.7 Kms./litre.

For cars the average fuel consumption ranges from 7 to 16 Km./litre but most of the cars cover a distance of 10 to 11 Kms per litre of fuel. Cars of foreign make were also considered in the survey, which explain for the lower average fuel consumption. The percentiles show that nearly 35% of the cars cover less than 9.5 Kms/litre and nearly 85% cover less than 11.5 Kms/litre , the mean average fuel consuption being 10.16 Km./litre of fuel.

4.4. Trip Distribution Analysis :

After the preliminary statistical analysis of the available data the next step is to formthe trip distribution matrix on its basis so that the actual trip distribution for the population can be estimated. Hence it is preferable to code the data according to the regions to which each response is related to enable easier compilation and identification of the trips made.

4.4.1 Zoning Of the City:

Such coding can best be achieved by dividing the entire city into several zones and assigning the zone number to the trip originating from that zone and destined for the

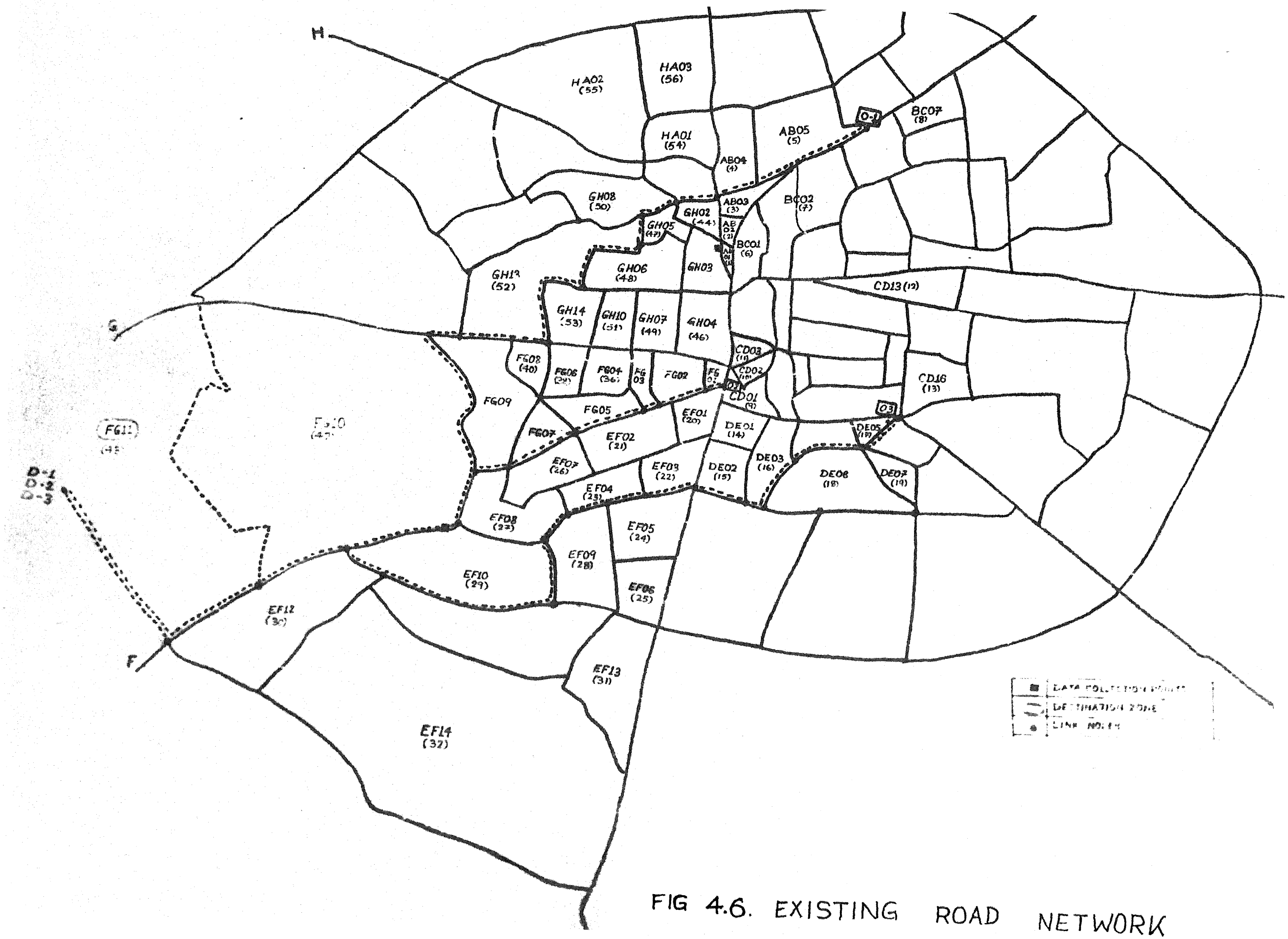

FIG 4.6. EXISTING ROAD NETWORK

industrial zone. The entire city was thus divided into 100 such zones based on the following guidelines :

i) Regions lying in the CBD being densely populated, the zonal area was kept smaller to avoid concentration of trip at a particular point.

ii) The demarcation between any two zones was done along the existing roads.

iii) The demarcation was also based on the landuse pattern of the region since home-to-workplace trips were to be considered.

The zones thus formed were assigned codes in the following manner :

All arterial roads of the city which are highway were identified and lettered in a clockwise direction begining with the northern road marked as 'A' in fig. 4.6. The zones lying between any two of these roads were numbered starting with the inner most zone and extending outwards. The letter of the neighbouring routes were also assigned to the zone code. Thus AB01 indicates the innermost zone lying between the arterial roads A and B. The coding of all the zones is shown in fig. 4.6.

4.4.2. Selection of Zones for O-D Matrix :

It was observed from the origin and destination data that no trip originated from some of the zones. Hence all

TABLE [illegible]. OBSERVED AND TOTAL TRIP DISTRIBUTION ARRAY.

ZONE	OBSERVED O-D ARRAY		TRIP DISTRIBUTION ARRAY	
	2[illegible]	4[illegible]	2[illegible]	4[illegible]
1	1	0	7	0
2	5	0	35	0
3	3	0	21	0
4	2	0	14	0
5	10	0	70	0
6	12	0	84	0
7	5	0	36	0
8	3	0	21	0
9	1	0	7	0
10	7	0	52	0
11	4	0	30	0
12	1	0	7	0
13	9	0	67	0
14	3	0	21	0
15	2	0	15	0
16	2	0	15	0
17	1	0	7	0
18	1	0	7	0
19	2	3	15	48
20	14	0	28	0
21	2	0	15	0
22	13	0	91	0
23	8	0	57	0
24	5	0	36	.0
25	0	3	0	48
26	4	1	28	16
27	12	1	80	16
28	19	0	133	0
29	6	0	42	0
30	3	0	21	0
31	2	4	15	64
32	2	0	13	0
33	1	0	7	0
34	5	0	35	0
35	9	0	42	.0
36	4	2	30	32
37	3	1	21	16
38	15	0	12	0
39	19	0	133	0
40	6	5	45	80
41	10	1	180	18
42	0	1	0	16
43	7	0	49	.0
44	0	1	7	16
45	0	4	28	66
46	1	0	7	.0
47	1	1	7	16
48	3	1	21	16
49	2	0	14	.0
50	2	2	14	32
51	31	0	217	0
52	4	0	28	.0
53	0	1	0	16
54	2	.0	14	.0

such zones were eliminated thus leaving 55 zones from which the trips originated and were destined for the industrial zone. These related zones were renumbered serially extending outwards between any two roads and proceeding clockwise.

Since destination was the industrial area for all the trips originating from various zones in the city the origin destination matrix was one consisting of trips originating from 55 zones and destined for the Industrial zone (coded as 43). The observed array is shown in table 4.6.

The origins of trips are invariably from zones whose landuse is residential. Zones 1,2,3,9 and 10 are in the CBD, zones 20 to 32 are in the newly developed areas lying in the south-East region of the city. Zones 46 to 53 are in the northern region of the city and are older than the rest but are thinly populated as the surrounding zones are occupied by government offices.

4.4.3. Peak Hour Trip Distribution :

The peak hour volume on the roads connecting the industrial zone with the city is necessary to assess the actual number of trips originating from various zones during the peak hour. The volume studies conducted in the past have shown that the peak hourly volume is generally between 8 to 15% of the average daily traffic. In the

volume studies conducted during the survey the peak hour flow was recorded for a period of two hours. Hence the peak hour volume was assumed to be 15% to 25% of the average daily traffic and a mean of 20% has been considered to compute the origin and destination array. The trip distribution array for the population was computed as follows :

The observed volume was considered to be 20% of the average daily traffic (ADT) then the ADT is five times the observed flow.

$$(ADT)_s = (PVOL)_s * 100/20 \tag{4.1}$$

where

$(ADT)_s$ = average daily traffic for s type vehicles.

s = 2 for scooters, mopeds and motorcycles

s = 4 for cars

$$(TTRD)_{mDs} = (OTRD)_{mDs} * (ADT)_s / (SSIZE)_s \tag{4.2}$$

where

$(TTRD)_{mDs}$ = total trip distribution array for trips made from m th zone to destination D by s type vehicle.

$(OTRD)_{mDs}$ = observed trip distribution array for trips made from m th zone to destination D by s type vehicle.

$(SSIZE)_s$ = Sample size of s type vehicle.

Heare the observed flow was as follows :

Type 2 vehicles : 606 vehicles / hour

Type 4 vehicles : 176 vehicles/hour

Then

$$(TTRD)_{mD2} = (OTRD)_{mD2} * 606 * 5/407$$

$$(TTRD)_{mD4} = (OTRD)_{mD4} * 176 * 5/43$$

The total trip distribution array is shown in table 4.6.

It is observed that the trip distribution array thus obtained consists of zones contributing to the worktrips and most of these zones are located in the thickly populated regions of city like the CBD and the South-western parts.

4.5 The Design of Routes :

Based on the total trip distribution array the planning for the routes is done to ply the buses from the city to the Industrial estate. The primary aim of such fixed route transit service is to transfer large number of passengers along corridors of high demand at a relatively low cost. Proposal for enhancing existing transit service are also put forth as a solution to urban traffic problems, a mean of saving energy and reducing travel time.

Here, the study being restricted to the analysis of impact of such extension of a bus systems, the process

involves planning of the bus routes so as to cater the zones in the total trip distribution array and determine the optimal number of buses to be plied; and the computation of the savings resulting from the modal shift of private vehicle owners to Public Transit System.

4.5.1. Planning of Bus Routes :

The growth of industries has always resulted in generation of more trips destined for these zones. The planning of bus routes catering to such trip makers is done so as to effect a modal shift from the present private vehicle trips to the public transit system. Since new routes thus planned, generate more traffic, it is necessary that the present structure be economically justified. The essential characteristics for such a route are :

i) It should be able to cater to as many zones as possible in the city.

ii) It should be economical to the operators and thepassengers.

iii) Origin of routes should be avoided in the CBD to minimise transfers.

iv) The routes should be direct.

v) The walking time should be minimum to reach the stops.

vi) The backtracking of routes should be avoided.

vii) Overlapping should be avoided as far as possible.

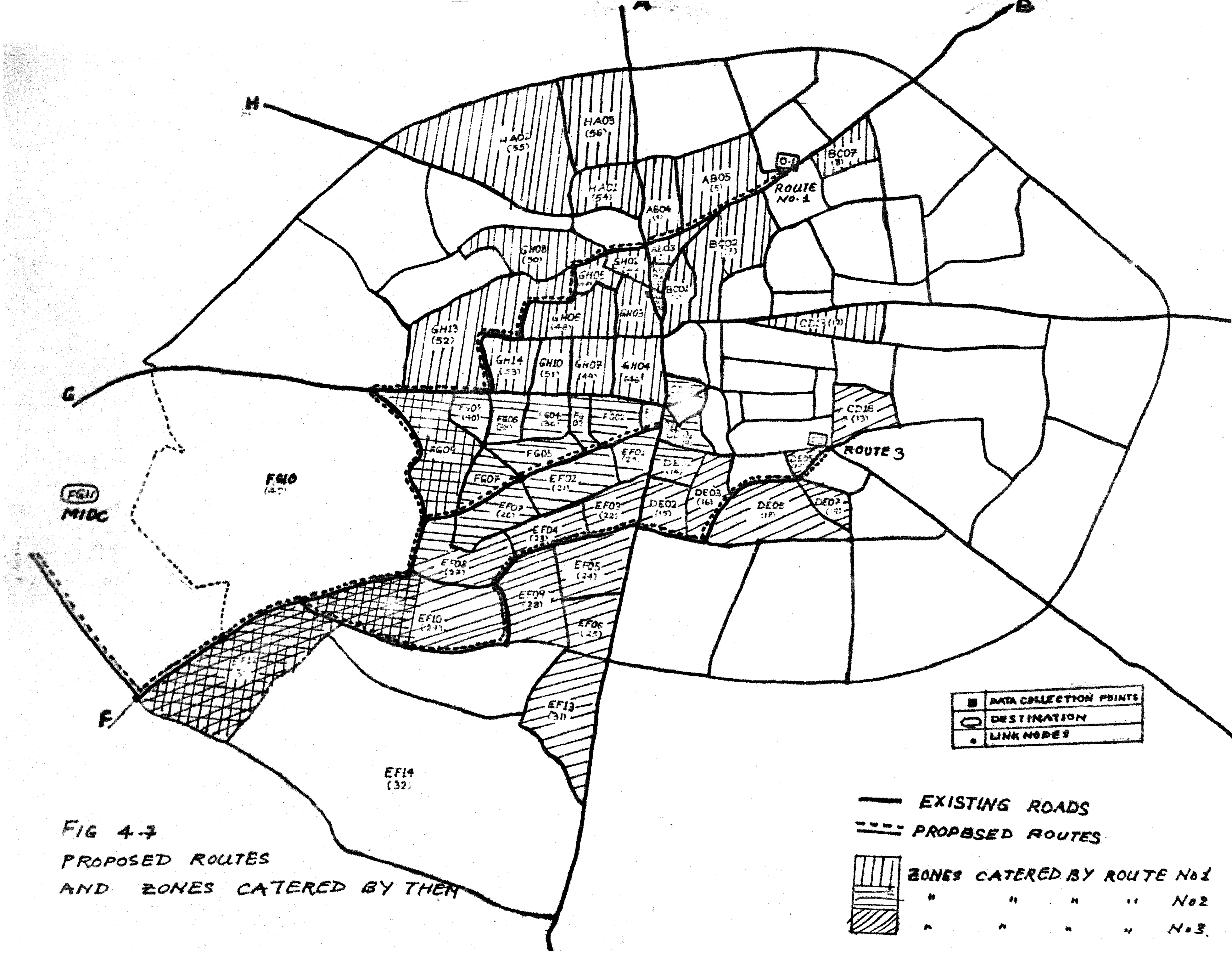

FIG 4.7
PROPOSED ROUTES
AND ZONES CATERED BY THEM

TABLE 4.7. ZONES CATERED BY VARIOUS ROUTES.

ROUTE NUMBER	ROUTE LENGTH (Kms)	ZONES CATERED BY THE ROUTE
1	17.2	1, 2, 4, 5, 6, 7, 8, 27, 36, 38, 40, 41, 42, 44, 45, 46, 47, 48, 49, 51, 52, 53.
2	11.5	9, 10, 11, 20, 21, 22, 23, 26, 27, 29, 33, 34, 35, 36, 37, 39, 41, 42, 46, 49.
3	14.5	13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 25, 26, 27, 29, 31.

To attain the above mentioned characteristics the strategy adopted for planning is as follows :

i) The origin zones are identified .

ii) The zones farthest from the industrial area with significant traffic were considered as destinations.

iii) With the terminal stations fixed up, the intermediate stations were inserted such that the length of the route is not greater than 1.5 times the direct distance between the terminals.

iv) The existing road network was considered.

v) The routes were generally along the main roads having higher capacity to enable faster movement.

vi) The routes were so located that there was a significant demand from zones lying on either sides of it.

vii) Routes with average link load factor greater than 0.5 were considered.

In all three such routes were selected and numbered as Route 1, 2, and 3. Table 4.7 shows the length of different routes and zones lying along it. These zones are also shown in Fig. 4.7.

4.5.2. Estimation of Demand :

After designing the routes, the demand along the routes at different zones is estimated by considering its proximity from the other routes. Demand from zones being

TABLE 1.2. DEMAND IN DIFFERENT ZONES ALONG ROUTE NO. 1.

S.No	ZONE	MOVEMENT 2W	4W	UTILITY FACTOR	DEMAND 2W	4W	TOTAL DEMAND
ALONG ROUTE NO. 1 :-							
1	1	7	0	1.0	7	0	7
2	2	33	0	1.0	33	0	33
3	4	13	0	1.0	13	0	13
4	5	66	0	1.0	66	0	65
5	6	33	0	1.0	33	0	33
6	7	33	0	1.0	33	0	33
7	8	20	0	1.0	20	0	20
8	27	26	7	0.5	13	3	15
9	36	52	0	0.5	26	0	26
10	38	20	7	1.0	20	7	27
11	40	125	0	1.0	125	0	125
12	41	39	33	1.0	39	33	72
13	42	46	7	0.4	18	2	20
11	44	46	0	1.0	45	0	46
15	45	0	7	1.0	0	7	7
16	46	0	26	0.5	0	13	13
17	47	7	0	1.0	7	0	7
18	48	7	7	1.0	7	7	14
19	49	20	7	0.8	16	5	21
20	51	13	7	1.0	13	7	20
21	52	203	0	1.0	203	0	203
22	53	20	0	1.0	20	0	20
ALONG ROUTE NO. 2 :							
1	9	7	0	1.0	7	0	7
2	10	46	0	1.0	46	0	46
3	11	26	0	1.0	26	0	25
4	20	13	20	0.8	10	16	26
5	21	92	0	0.7	64	0	64
6	22	13	0	0.2	2	0	2
7	23	85	0	0.1	8	0	8
8	26	20	0	0.8	16	0	16
9	27	26	7	0.5	13	3	16
10	29	125	0	0.4	50	0	50
11	33	13	0	0.2	2	0	2
12	34	7	0	1.0	7	0	7
13	35	33	0	1.0	33	0	33
14	36	52	0	0.5	26	0	26
15	37	26	13	1.0	26	13	39
16	39	105	0	1.0	105	0	105
17	41	39	33	0.3	9	8	17
18	42	46	7	0.3	13	2	15
19	46	0	26	0.5	0	13	13
20	49	20	7	0.2	4	1	5
ALONG ROUTE NO. 3 :-							
1	13	7	0	1.0	7	0	7
2	14	52	0	0.6	31	0	31
3	15	20	0	1.0	20	0	20
4	16	13	0	1.0	13	0	13
5	17	13	0	1.0	13	0	13
6	18	7	0	1.0	7	0	7
7	19	7	0	1.0	7	0	7
8	20	13	20	0.2	2	4	6
9	21	92	0	0.3	27	0	27
10	22	13	0	0.8	10	0	10
11	23	85	0	0.9	76	0	76
12	25	33	0	1.0	33	0	33
13	26	20	0	0.2	4	0	4
14	27	26	7	0.5	13	3	16
15	29	125	0	0.6	74	0	74
16	31	20	0	1.0	20	0	20

catered by more than one route is assessed by considering the utility factor. This factor is defined as the ratio of the length of the proposed route coinciding with the zone in question to the total length of all routes coinciding with that zone.

$$(\text{uFACTOR})_{ik} = (\text{LENGTH})_{ik} \Big/ \sum_{k=1}^{R} (\text{LENGTH})_{ik} \qquad (4.3)$$

where $(\text{uFACTOR})_{ik}$ = utility factor of i th zone touching route k.

The factor is based on the principle that, a person originating from a zone catered by two routes prefers to travel by the route close to his residence. Based on this utility factor the demand is calculated as follows :

$$(\text{FDEM})_{iks} = (\text{uFACTOR})_{ik} * (\text{TTRD})_{iks} \qquad (4.4)$$

where $(\text{FDEM})_{iks}$ is the final demand in zone i from owners of s type vehicles on k th route.

and $(\text{TTRD})_{iks}$ is obtained from equation (4.2).

The demand for the different zones lying on each route is shown in Table 4.8.

4.6. Variables and Parameters in the Experiment :

The strategy adopted here, to evaluate the savings in fuel consumption, is to vary a few parameters like the percentage of modal shift, value of time, number of buses

TABLE 4.9. LINK LOAD FACTORS ON ROUTE NO. 1.

S#	L-N	DEM.	LOAD FACTOR FOR DIFF. NO. OF BUSES 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1- 2	7	0.12	0.06	0.04	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
2	2- 4	33	0.67	0.33	0.22	0.17	0.13	0.11	0.10	0.08	0.07	0.07	0.06	0.06	0.05	0.05	0.04
3	4- 5	13	0.88	0.44	0.29	0.22	0.18	0.15	0.13	0.11	0.10	0.09	0.08	0.07	0.07	0.06	0.06
4	5- 6	66	1.98	0.99	0.66	0.50	0.40	0.33	0.28	0.25	0.22	0.20	0.18	0.17	0.15	0.14	0.13
5	6- 7	33	2.53	1.27	0.84	0.63	0.51	0.42	0.36	0.32	0.28	0.25	0.23	0.21	0.19	0.18	0.17
6	7- 8	33	3.08	1.54	1.03	0.77	0.62	0.51	0.44	0.39	0.34	0.31	0.28	0.26	0.24	0.22	0.21
7	8-27	20	3.42	1.71	1.14	0.85	0.68	0.57	0.49	0.43	0.38	0.34	0.31	0.28	0.26	0.24	0.23
8	27-36	17	3.70	1.85	1.23	0.92	0.74	0.62	0.53	0.46	0.41	0.37	0.34	0.31	0.28	0.26	0.25
9	36-38	26	4.13	2.07	1.38	1.03	0.83	0.69	0.59	0.52	0.46	0.41	0.38	0.34	0.32	0.30	0.28
10	38-40	27	4.58	2.29	1.53	1.15	0.92	0.76	0.65	0.57	0.51	0.46	0.42	0.38	0.35	0.33	0.31
11	40-41	125	6.67	3.33	2.22	1.67	1.33	1.11	0.95	0.83	0.74	0.67	0.51	0.56	0.51	0.48	0.44
12	41-42	72	7.87	3.93	2.62	1.97	1.57	1.31	1.12	0.98	0.87	0.79	0.72	0.66	0.61	0.56	0.52
13	42-44	20	8.20	4.10	2.73	2.05	1.64	1.37	1.17	1.03	0.91	0.82	0.75	0.68	0.63	0.59	0.55
14	44-45	46	8.97	4.48	2.99	2.24	1.79	1.49	1.28	1.12	1.00	0.90	0.82	0.75	0.69	0.64	0.60
15	45-46	7	9.08	4.54	3.03	2.27	1.82	1.51	1.30	1.14	1.01	0.91	0.83	0.76	0.70	0.65	0.61
16	46-47	13	9.30	4.65	3.10	2.32	1.86	1.55	1.33	1.16	1.03	0.93	0.85	0.77	0.72	0.66	0.62
17	47-48	7	9.42	4.71	3.14	2.35	1.88	1.57	1.35	1.18	1.05	0.94	0.86	0.78	0.72	0.67	0.63
18	48-49	14	9.65	4.82	3.22	2.41	1.93	1.61	1.38	1.21	1.07	0.97	0.88	0.80	0.74	0.69	0.64
19	49-51	21	10.00	5.00	3.33	2.50	2.00	1.67	1.43	1.25	1.11	1.00	0.91	0.83	0.77	0.71	0.67
20	51-52	20	10.33	5.17	3.44	2.58	2.07	1.72	1.48	1.29	1.15	1.03	0.94	0.86	0.79	0.74	0.69
21	52-53	203	13.72	6.86	4.57	3.43	2.74	2.29	1.96	1.71	1.52	1.37	1.25	1.14	1.06	0.98	0.91
22	53-57	20	14.05	7.02	4.68	3.51	2.81	2.34	2.01	1.76	1.56	1.41	1.28	1.17	1.08	1.00	0.94

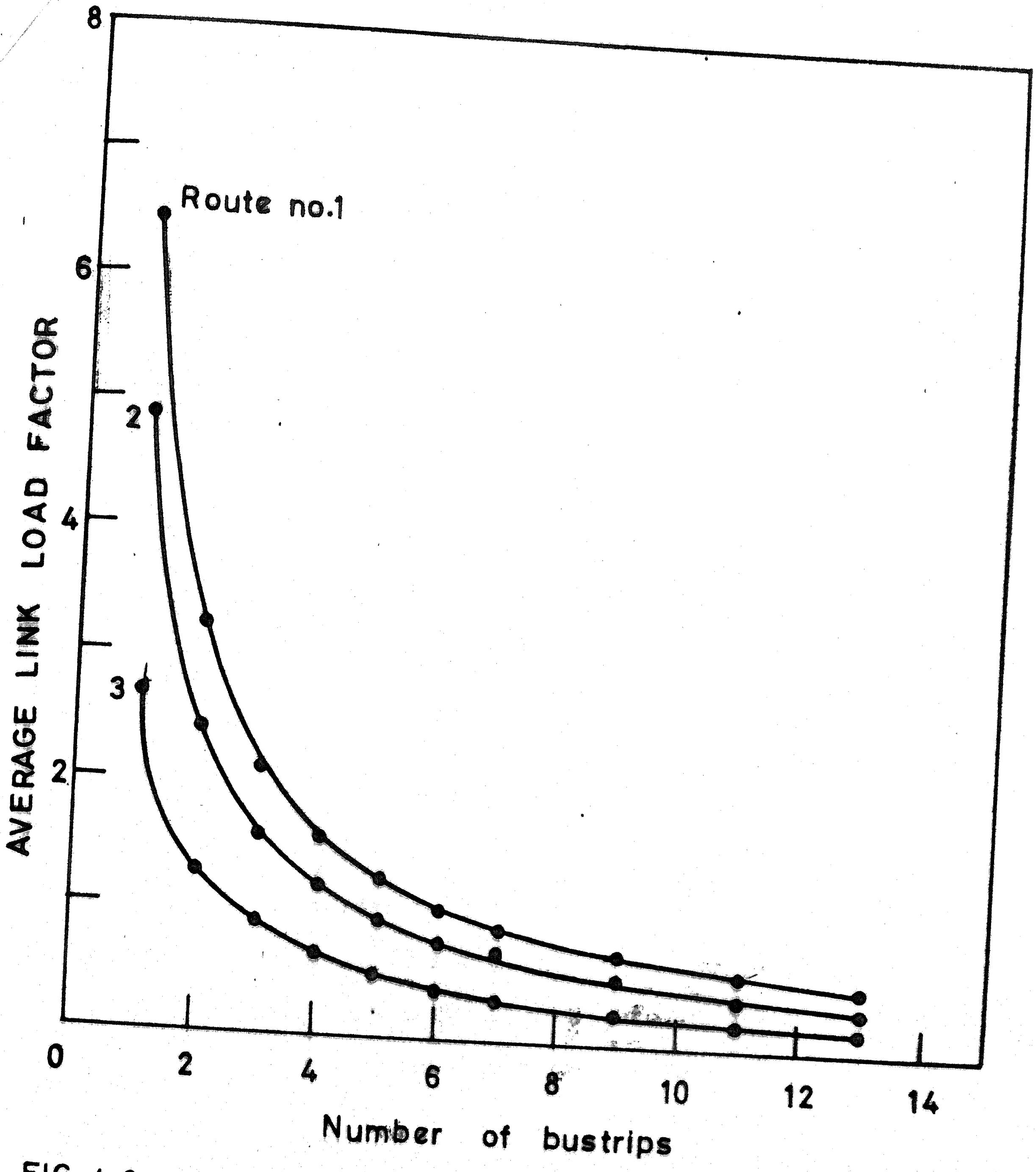

FIG. 4.8 VARIATION OE AVERAGE LINK LOAD FACTOR WITH NO. OF BUSTRIPS

$(DEM)_{pnk}$ = the demand on pth node of n th link of k th route.

$(NBUS)_k$ = number of buses being plied on the k th route.

$(CAPBUS)_k$ = capacity of the bus on k th route.

The link load factor for each such link on all the three routes have been determined and is shown in Table 4.9.

ii) Average Link Load Factor :

It is defined as the ratio of the sum of all link load factors of a given route to the number of links in it.

$$(ALF)_k = \sum_{p=1}^{N} \sum_{q=p+1}^{N-1} (LINKLF)_{pqk} / (NLINK)_k \quad (4.7)$$

where $(ALF)_k$ = average load factor of k th route.

$(NLINK)_k$ = number of links on k th route.

The link load factor is obtained from equation (4.5). This factor gives an idea of the capacity utilisation of the whole route and is of importance to the operators, since it is observed that it is not profitable to ply a bus on a route having an average loadfactor less than 0.5.

The variation of loadfactor for different number of bus trips on all the three routes is shown in Fig. 4.8. It is observed that there is an exponential fall in the loadfactor initially but remains almost constant at higher

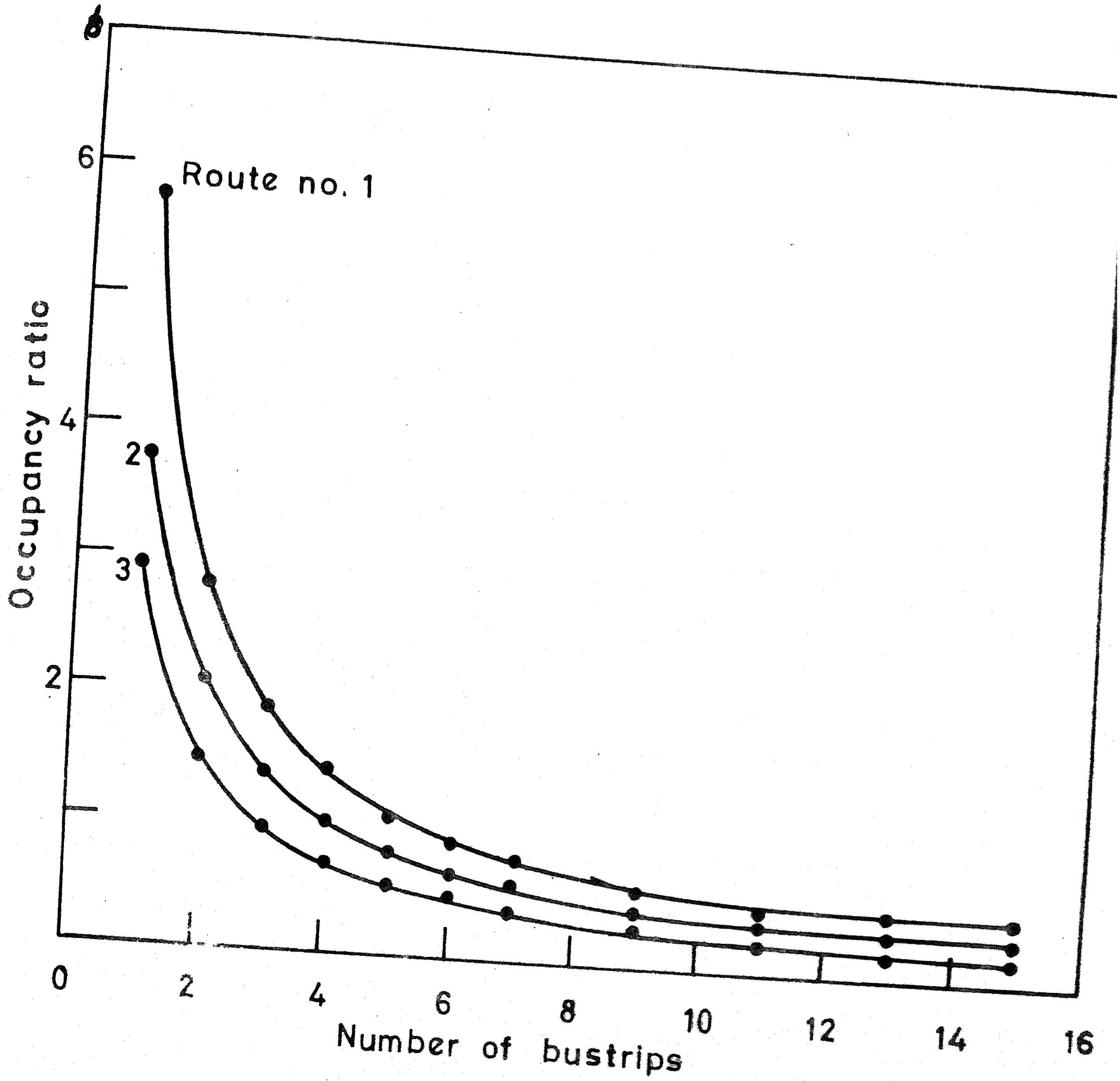

FIG. 4.9 VARIATION OF OCCUPANCY RATIO WITH NUMBER OF BUSTRIPS

number of bus trips indicating thet , at higher number of bus trips the capacity utilisation is lesser

iii) Occupancy Ratio

Another factor defined as a measure of capacity utilization is occupancy ratio and is the ratio of the seat-Kms. sold to seat-Kms. offerred.

$$(\text{OCRATIO})_k = \frac{\sum_{p=1}^{(\text{NLINK})_k} (\text{FLOW})_{pqk} * (\text{LLINK})_{pqk}}{(\text{NBUS})_k * (\text{CAPBUS})_k * (\text{LROUTE})_k} \qquad (4.8)$$

where

$(\text{OCRATIO})_k$ = Occupancy ratio of k th route

$(\text{LLINK})_{pqk}$ = link length betwen nodes p and q on k th route

$(\text{LROUTE})_k$ = total length of route k

The occupancy for the different routes is shown in Fig. 4.9. Since the distance travelled by a passenger is considered in this factor, it is found to be a better measure of utilization from the operators point ofview, since it is not profitable to move large number of passengers on short distances due to the under utilization of the vehicles on the previous links.

4.6.2. Time Variables

The time variables form to be important components of the proposed

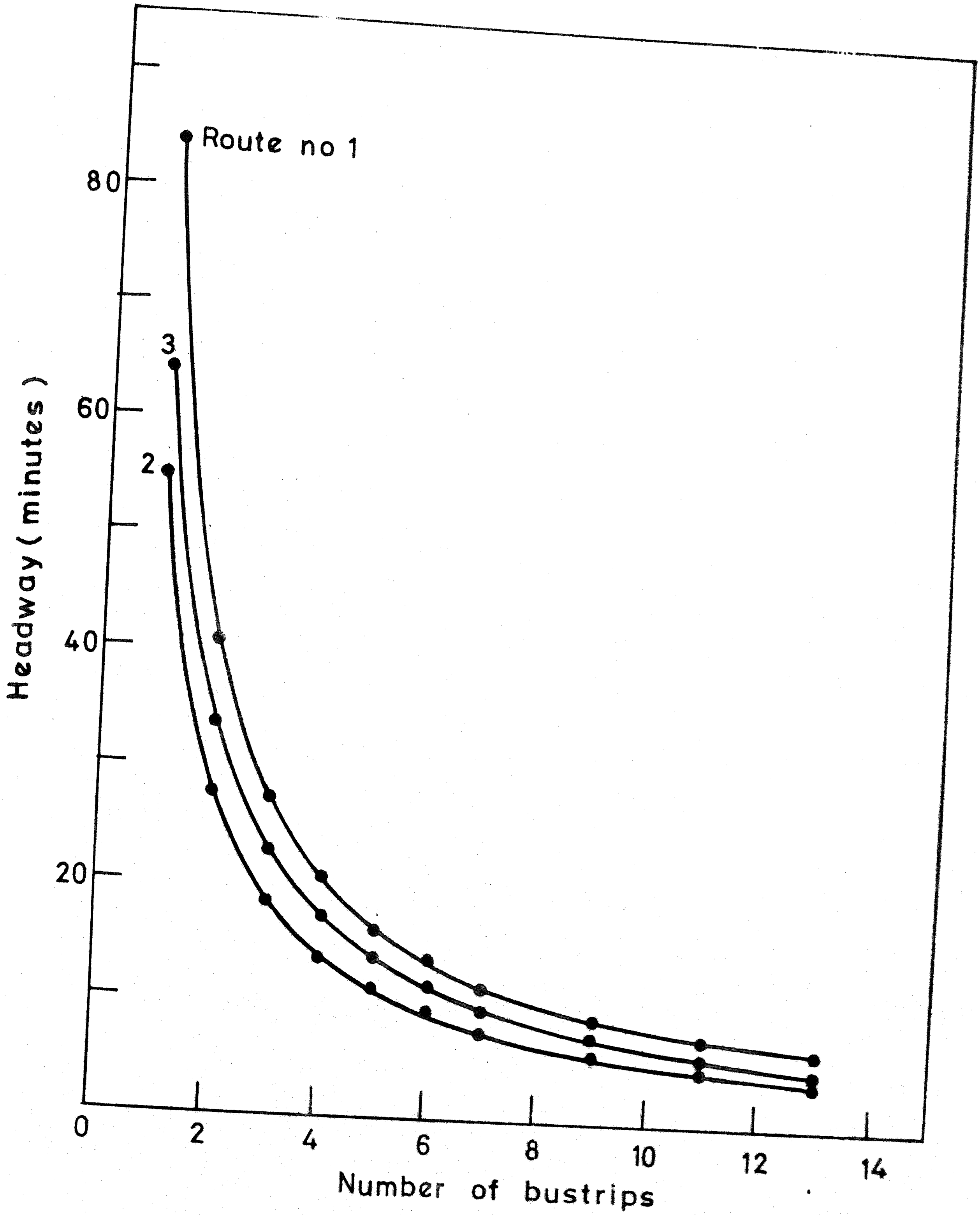

FIG. 4.10 VARIATION OF HEADWAY WITH NO. OF BUSTRIPS

experiment, since the travel cost is also a function of them. The variables considered here are :

(i) Headways

(ii) Average waiting time

(iii) Travel time by bus

(iv) Travel time by private vehicles

(v) Additional travel time by bus

These different time variables are computed as follows :

(i) Headway :

Headway is the spatial separation between two buses on a given route and is quantified by time or the distance, by which the buses are spaced. Here the time headways have been considered during the study.

Let

$$(RTIME)_k = 2 * (LROUTE)_k \,/\, (MBUSP)_k + (LOTIME)_D \qquad (4.9)$$

Then $\quad (HWAY)_k = (RTIME)_k / (NBUS)_k$

where $(RTIME)_k$ = roundtrip time of the bus on the k th route.

$(MBUSP)_k$ = mean bus speed on the k th route.

$(LOTIME)_D$ = lay over time at the destination D

$(HWAY)_k$ = Headway of buses on the k th route. Lay over time is the time elapsed between the arrival of the bus at the destination and its departure for the return trip. Thus on a given route, for mean bus speed the headways can be determined. Fig. 4.10 shows the variation of the headways with

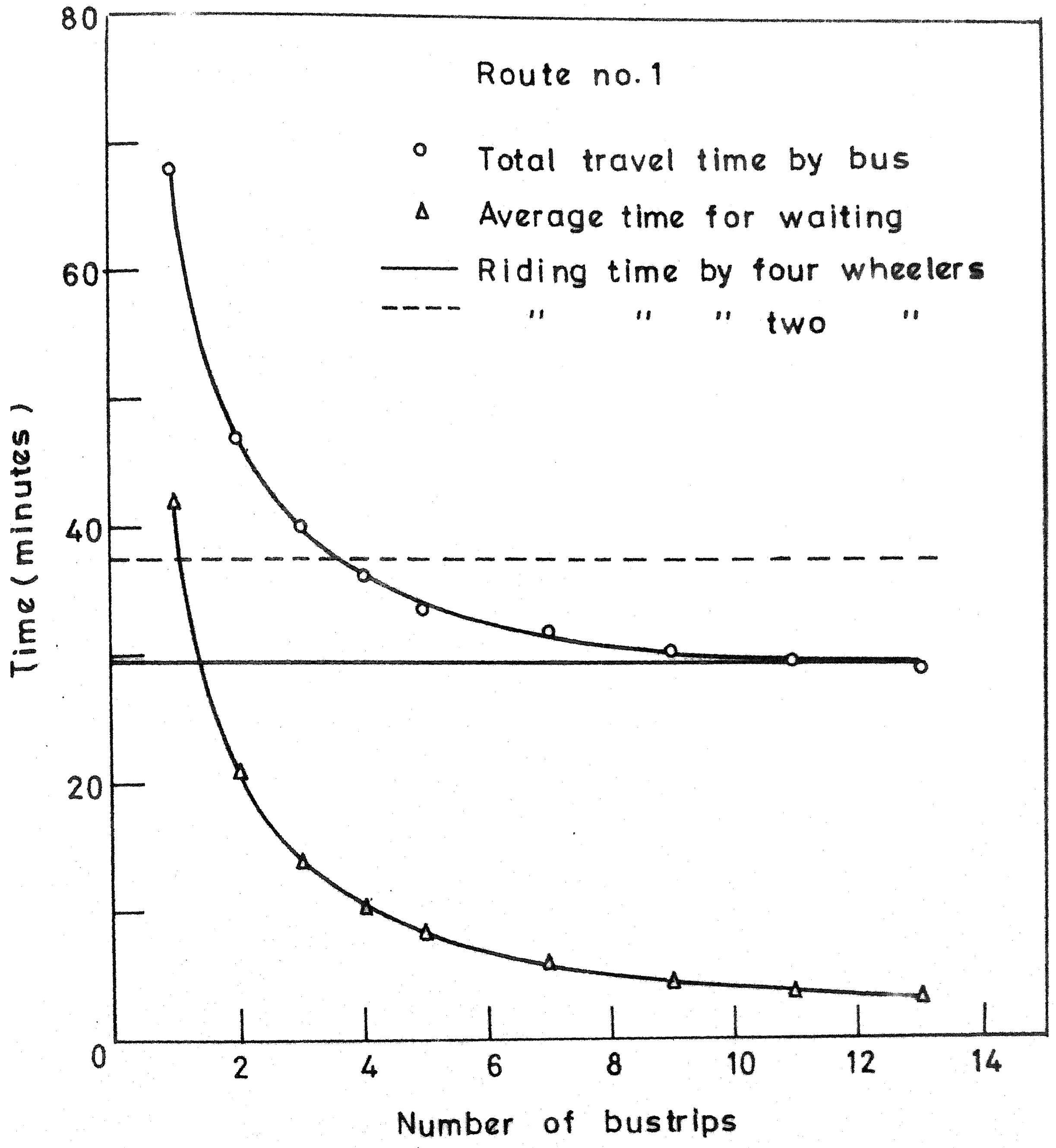

FIG. 4.11 VARIATION OF WAITING AND TRAVEL TIMES WITH NUMBER OF BUSTRIPS

the number of buses being plied on that route. With increase in the number of buses, the lesser will be the headway.

ii) Average Waiting Time :

It is the time elapsed between the arrival of a passenger at a bus stop and the time at which he boards the earliest arriving bus. Here it is assumed that the average waiting time is half the headway. This is based on the fact that, if a passenger arrives such that he boards the bus immediately his waiting time will be zero. Similarly if he arrives such that the last bus has just left, his waiting time will be the headway of the next bus. Hence a mean of these waiting times is considered.

$$(AWATIM)_k = (HWAY)_k / 2 \qquad (4.10)$$

where

$(AWATIM)_k$ = the average waiting time on route k when NBUS buses are being plied. The variation of average waiting time for different number of bus trips is shown in figure 4.11 and is observed that the average waiting time reduces with the number of bus trips.

The waiting time lies between zero and the headway of the bus provided the passenger is able to board the first available bus. On certain routes passing through the CBD, the demand is heavy during peak periods. In such instances the passenger may not be able to board the first arriving

bus if it is already overloaded. But for the routes under consideration, the demand is not so heavy, hence it was assumed that the passenger will board the first available bus. For the average waiting time was used in computing the total travel time by bus and the cost associated with it. For the route already existing if the arrival gap distribution is known, it is possible to work out the waiting time distribution.

iii) Bus Travel Time :

It is the elapsed time between the arrival time of a passenger and the time at which he reaches the destination. It thus includes the waiting time and the journey time.

$$(BTRTIM)_k = (AWATIM)_k + (RTIME)_k/2 \qquad (4.11)$$

where $(BTRTIM)_k$ = Travel time by bus on k th route

The variation of travel time for different number of buses is shown in 4.11. Since the journey time is constant for a given route, the bus travel time is a function of the average waiting time, and hence reduces with increase in the frequency of bustrips.

iv) Travel Time by Private Vehicles :

It is the time taken by a person to make a home-to-workplace trip by his vehicle.

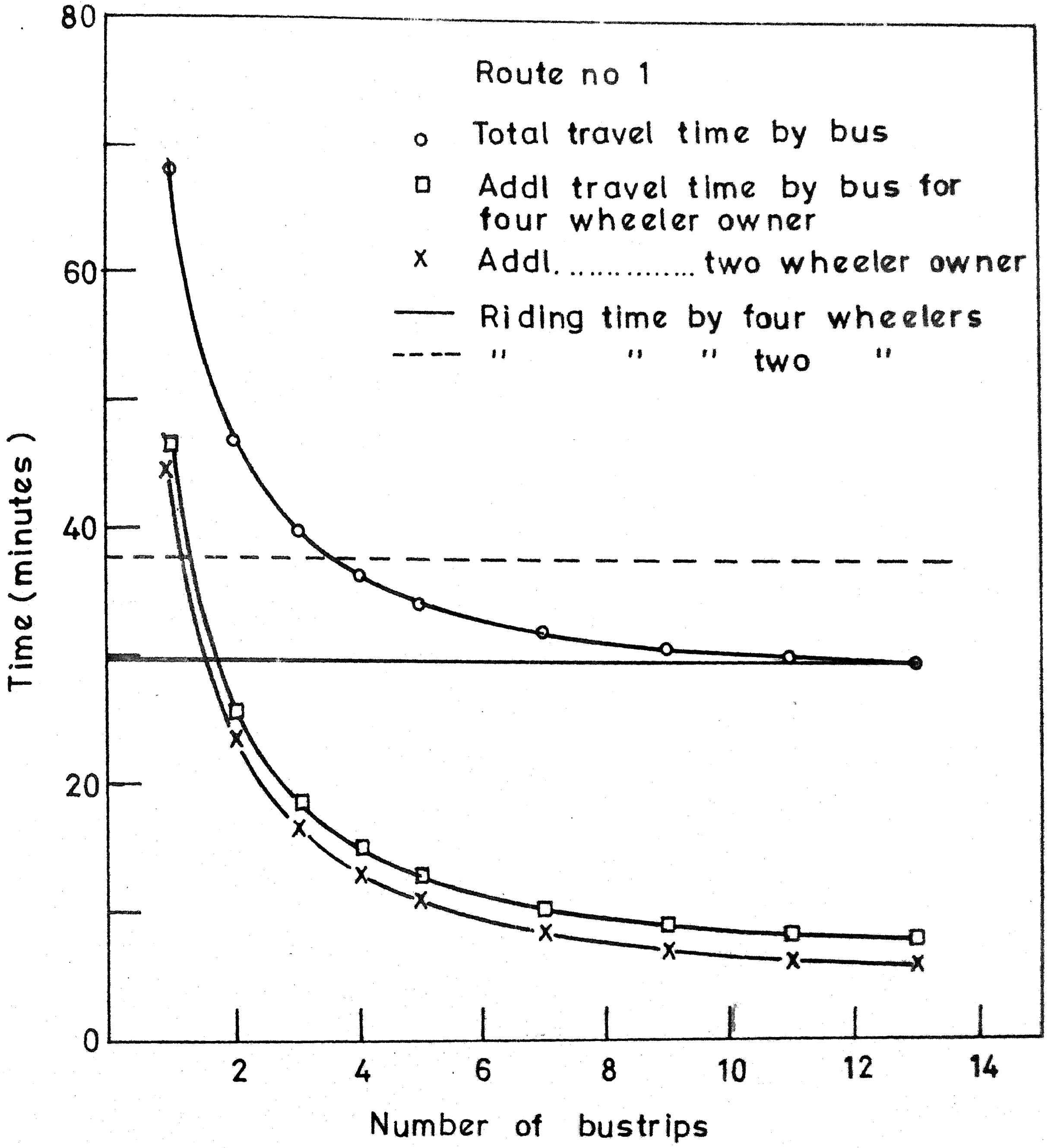

FIG.4.12 VARIATION OF ADDITIONAL TRAVEL TIME BY BUS WITH NUMBER OF BUSTRIPS

$$(TRPTIM)_{sk} = (MTRLEN)_{sk} / (MPVSP)_{sk} \qquad (4.12)$$

$(TRPTIM)_{sk}$ = Travel time by s type vehicle on k th route.

$(MPVSP)_{sk}$ = Mean speed of s type vehicle on kth route.

$(MTRLEN)_{sk}$ = Mean triplength made by s type vehicle owner on k th route.

Here the mean travel time for two wheelers users was 20 minutes and 18 minutes for car users.

The mean travel times by two wheelers and four wheelers/are shown in fig. 4.11.

(v) Additional Travel Time :

It is the additional travel time spent by a person on travelling by bus instead of his private vehicle and hence is the difference between the travel time by bus and the travel time by private vehicle.

$$(ADTIME)_{sk} = (BTRTIM)_{k} - (TRPTIM)_{sk} \qquad (4.13)$$

where

$(ADTIME)_{sk}$ is the additional travel time spent by a person owning s type vehicle, but travelling by bus on route k. The additional time is shown in fig. 4.12. Since the travel time by private vehicles is constant for a given route, additional travel time is a function of the waiting time.

4.6.3. Cost Variables :

In order to evalute the savings resulting from the shift of private vehicle owners to the bus transit system, it is necessary to determine the various costs resulting from the time and the passenger movement. The different costs thatcomprise the analysis are :

i) Unit operating cost

ii) Additional cost by bus

iii) Total cost of travel by bus

iv) Operating cost of Private vehicles

These costs are evaluated as follows :

(i) Unit Operating Cost :

It is the cost incurred by a passenger on travelling a unit distance by a bus and its depends on the number of the passengers being carried by the bus and the number of busses being plied.

$$(UOC)_k = (OPCOST)_k \, / \, (NBUS)_k * (CAPBUS)_k * (ALF)_k \qquad (4.14)$$

where

$(UOC)_k$ = unit operating cost in Rs. per passenger per Km.

$(OPCOST)_k$ = average operating cost of bus in Rs. per Kms. on k th route.

$(CAPBUS)_k$ = capacity of the bus on k th route.

$(ALF)_k$ = average link load factor.

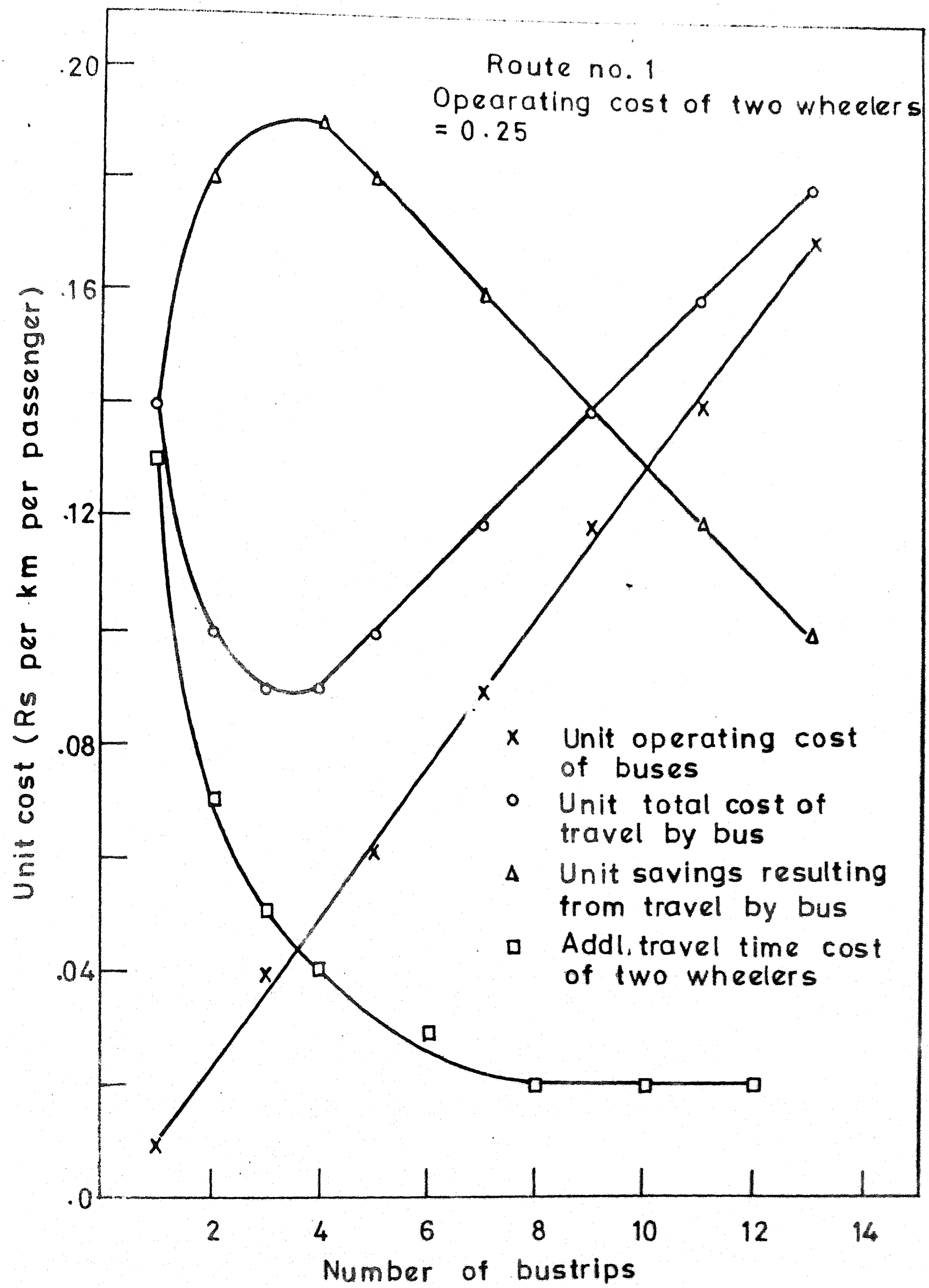

FIG. 4.13 UNIT COST CURVES FOR TWO WHEELERS

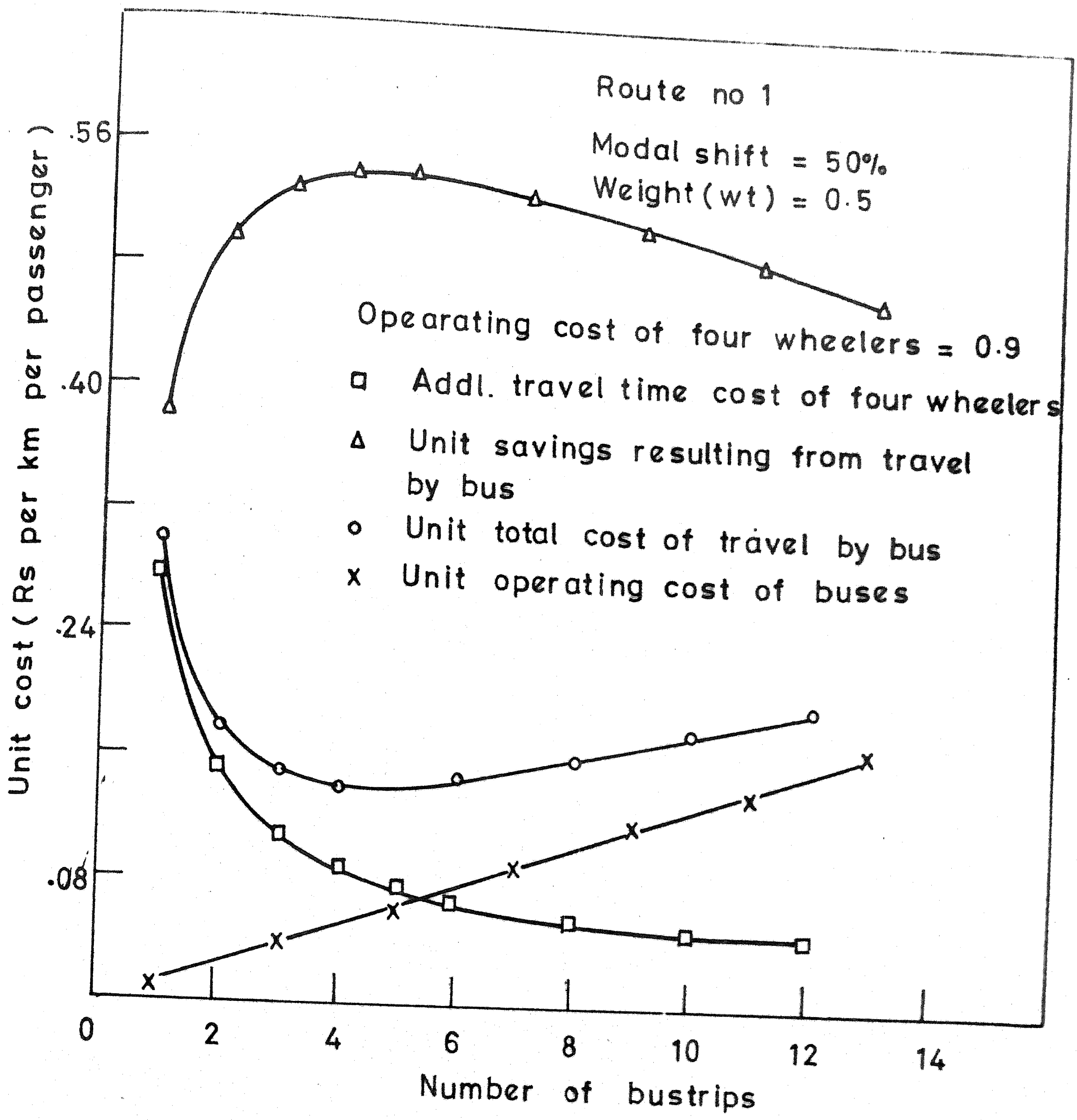

FIG. 4.14 UNIT COST CURVES FOR FOUR WHEELERS

The unit operating cost variation for route no. 1 is shown in fig. 4.13-14. The load-factor reduces with an increase in the number of buses and hence the unit cost of operation increases since $(OPCOST)_k$ remains constant for a given route.

(ii) Additional Cost by Bus :

It is the additional cost incurred by a passenger on travelling by bus instead of using his own vehicle.

Since a person has to wait at a stop to board the bus and also has to spend more time on board due to the lower speed of the bus, it was decided to assign a cost to this additional travel time. This assignment has been based on the income of the passenger from which the unit cost can be evaluated.

$$(UCTIME)_s = (INCOME)_s \, / \, (DAY)_s * (HOUR)_s \qquad (4.15)$$

where

$(UCTIME)_s$ = unit cost of time of a person owning s type vehicle in Rs. / hour

$(INCOME)_s$ = monthly income of a person owning s type vehicle

Here $(INCOME)_2 = 1000$; $(INCOME)_4 = 2000$

$(HOUR)_s$ = Number of working hours a day

$(DAY)_s$ = Number of working days in a month.

$$(AUCOST)_{sk} = (UCTIME)_s * (ADTIME)_{sk} \, / \, (LROUTE)_k \qquad (4.16$$

$(AUCOST)_{sk}$ = additional unit cost incurred by a passenger owning s type vehicle but travelling by bus on route k.

The cost variation for route no. 1 is represented in fig. 4.13-14. It is observed that the additional unit cost reduces with increase in the number of bustrips which is due to the reduction in waiting time. Value of time of car owners being higher than that of two wheeler owners the former's additional cost is also higher .

iii) Total Cost of Travel by Bus :

It is the total cost incurred by a person owning s type vehicle but travelling by bus and is the sum of the unit operating cost and the unit additional cost of travel by bus.

$$(TOCOST)_{sk} = (UOC)_k + (AUCOST)_{sk} \qquad (4.17)$$

where

$(TOCOST)_{sk}$ = unit total cost of travel for a person owning s type vehicle in Rs. per passenger per Km.

Since the unit operating cost increases with the number of buses and so falls the unit additional cost, the total cost curve exhibits a minima as shown in fig. 4.13-14 at which the total unit cost of travel is minimum.

(iv) Operating Cost of Private Vehicles :

It is cost incurred by a person on travelling a unit

distance on a privately owned vehicle. This cost is estimated on the average fuel consumption of the vehicle and additional expenditure on it like maintenance.

Let, $(UMCOST)_s = (MNCHRG)_s / (26 * 2 * (TLENGTH)_s$ (4.18)

where

$(UMCOST)_s$ = unit maintenance cost in Rs. per Km. of s type vehicle.

$(MNCHRG)_s$ = monthly maintenance charges of s type vehicle.

$(TLENGTH)_s$ = Average trip length of s type vehicle.

Considering 26 working days in a month and two trips a day the unit maintenance cost is evaluated.by equation (4.8)

$(OCPVEH)_s = (PRICE)/(AVDC)_s + (UMCOST)_s$ (4.19)

where

$(OCPVEH)_s$ = operating cost of s type vehicle in Rs./Km.

(PRICE) = price of fuel in Rs. per litre.

$(AVDC)_s$ = average distance covered per litre of fuel consumed in Kms. per litre.

The following values were assigned to determine the operating cost of two and four-wheelers:

(PRICE) = 6.70

$(MNCHRG)_2 = 20.00$; $(MNCHRG)_4 = 100.00$

$(TLENGTH)_2 = 8.84$ Km.; $(TLENGTH)_4 = 8.38$ Km.

$(AVDC)_2 = 33.41$ Km. per litre ; $(AVDC)_4 = 10.16$ Km per litre.

The resulting operating cost was

$(OCPVEH)_2 = 0.254$ Rs. per Km.

$(OCPVEH)_4 = 0.89$ Rs. per Km.

Fig. 4.13-14 shows the unit operating cost of two and four wheelers. These operating costs are used to compute the savings resulting from the use of public transit system.

4.6.4. Unit Savings Variables :

It is the profit resulting on travelling by a bus instead of the private vehicle and hence is the difference of the operating cost of private vehicles and the total cost of travel by bus.

$$(SAV)_{sk} = (OCPVEH)_s - (TOCOST)_{sk} \qquad (4.20)$$

where

$(SAV)_{sk}$ = is the unit savings for s type vehicle owners but travelling by bus in Rs. per passenger per Km.

$(OCPVEH)_s$ and $(TOCOST)_{sk}$ can be obtained from equations (4.17) and (4.19) respectively. The unit savings for two and four-wheelers are shown in Fig. 4.13-14. Since the operating cost of private vehicles is constant, the savings curve will also show a maxima corresponding to the minima of the unit total cost curve. The operating cost of cars being higher, the savings resulting from their modal shift is higher.

4.7 Design Parameters :

The impact of a proposed strategy can be best understood by varying the relevant parameters and studying their effect at different levels of variation so as to evaluate the feasibility of its implementation.

In the experiment proposed here it was decided to vary the following parameters :

(i) Number of bustrips

(ii) Value of time

(iii) Percentage modal shift

The selection of these parameters and their control is presented here.

(i) Number of Bustrips :

The number of bustrips affects the loadfactors; headways, average waiting time, travel time by bus, additional cost, operating cost and total cost. Hence it was decided to vary the number of bustrips and study the effect on all these variables. Initially the number of bustrips was varied from 1 to 15 for each route to evaluate the average link load factors.

(ii) Percentage of Modal Shift :

Since the proposed system was to be studied for the effect of modal shift on fuel consumption, it would be desirable to observe the effect of different percentages

of modal shift from private vehicles to public transit and the cost of travel, total savings and optimal number of bustrips can be determined.

(iii) Weight for Value of Time :

In the estimation of the additional cost of time incurred by a passenger, an average monthly income was assumed. But it would be more logical to vary this value of time since its value during working hours is not the same as off-duty hours. Hence this value of time was also varied.

4.8 Run of the Experiment :

After deciding the control parameters as the number of bustrips, percentage of modal shift and value of time, the experiment was run by varying these parameters in their respective ranges.

4.8.1 Variation of Parameters

The experiment was initially run for 15 bustrips and the average link load factors were determined for all the three routes and it was found that for these many bustrips the load factors fell below 0.5 on all the three routes. Since it is not desirable to operate buses below this level only 13 bustrips were considered and varied during the later stage of the experiment by starting with 1 bustrip and an increment of 1.

The percentage of modal was varied from 20% to 100% to study the impact of the extremeties of the shift on the cost. The variation was done with an increment of 10%.

The weight value of time was also varied to study its effect on the cost. The variation ranged between 0.1 and 0.9 with an increment of 0.2. Considering 26 working days in a month and 8 hours a day, the value of time for two-wheelers and four-wheelers was Rs. 4.8 per hour and Rs. 9.6 per hour respectively. Weights of 0.1, 0.3, 0.5, 0.7 and 0.9 were assigned to values of different runs of the experiment.

The sequence of run with all the three parameters in combination was as follows :

(i) The modal shift was increased in steps of 10% starting with 20%.

(ii) For a particular modal shift the value of time was stepped up by 0.2 starting with 0.1.

(iii) For a given modal shift and weight for value of time, the number of buses was varied from 1 to 13 and the following variables determined :

(1) Average load factor

(ii) Headway

(iii) Average waiting time

(iv) Travel time by bus

(v) Additional travel time

(vi) Unit operting cost

(vii) Unit additional cost of time

(viii) Unit total cost

(ix) Unit Savings

The number of buses corresponding to the minimum total cost was fixed as the optimum for different combinations of modal shift and value of time for all the three routes.

4.9. Analysis of Results

The results of the experiment can be interpreted better if represented graphically. Here the results are analysed for the effect of modal shift and the weight for time on cost and time variables.

4.9.1. Effect on time

The various time variables in the experiment are independent of the modal shift and the weight for time and hence remain unchanged.

4.9.2. Effect on Costs

The various costs viz., the operating cost, additionaltravel time cost and the total cost are affected by either of the parameters. The costs have been computed for the total demand and hence are known as the total cost

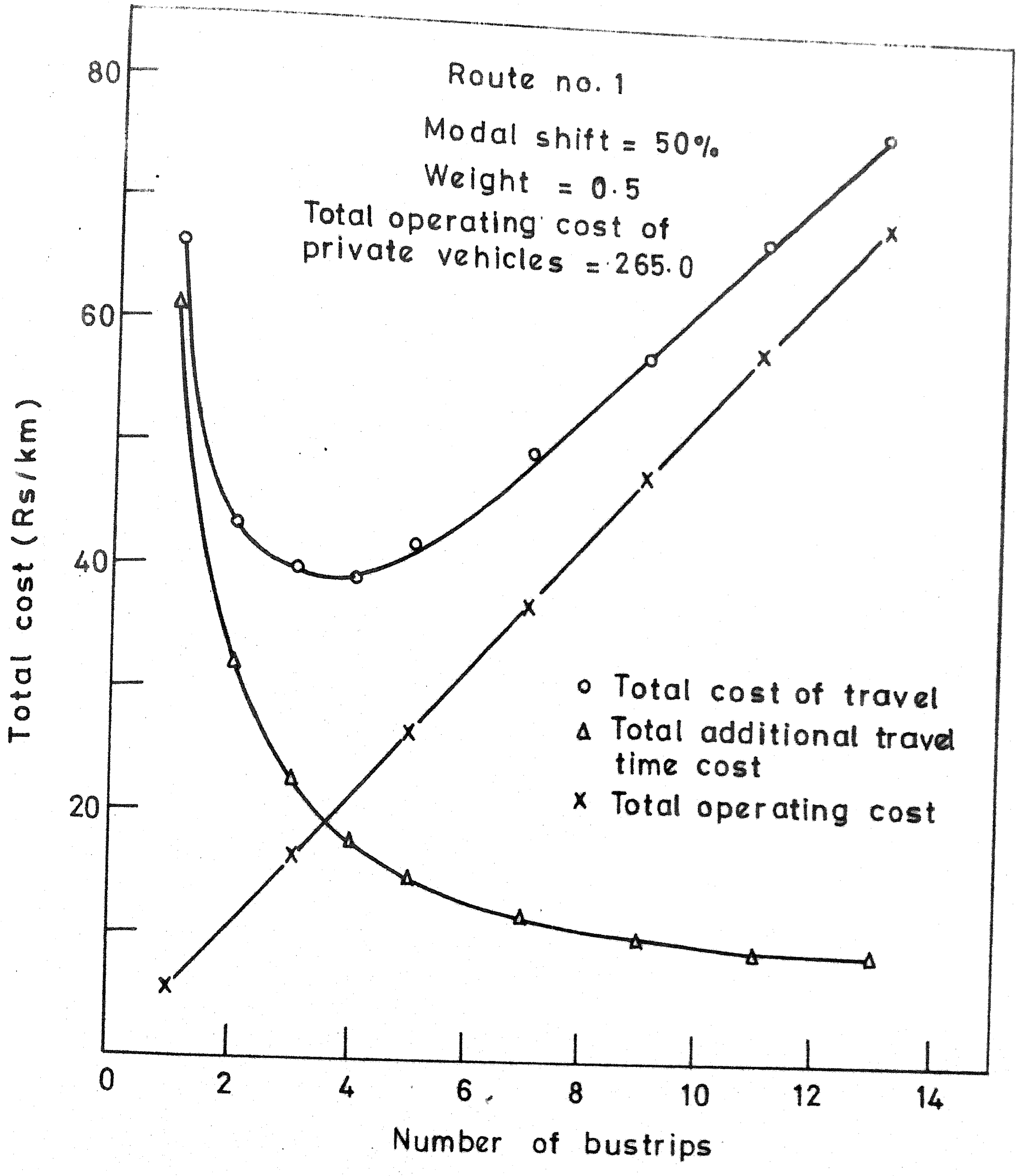

FIG. 4.15 TOTAL COST CURVES VARIATION

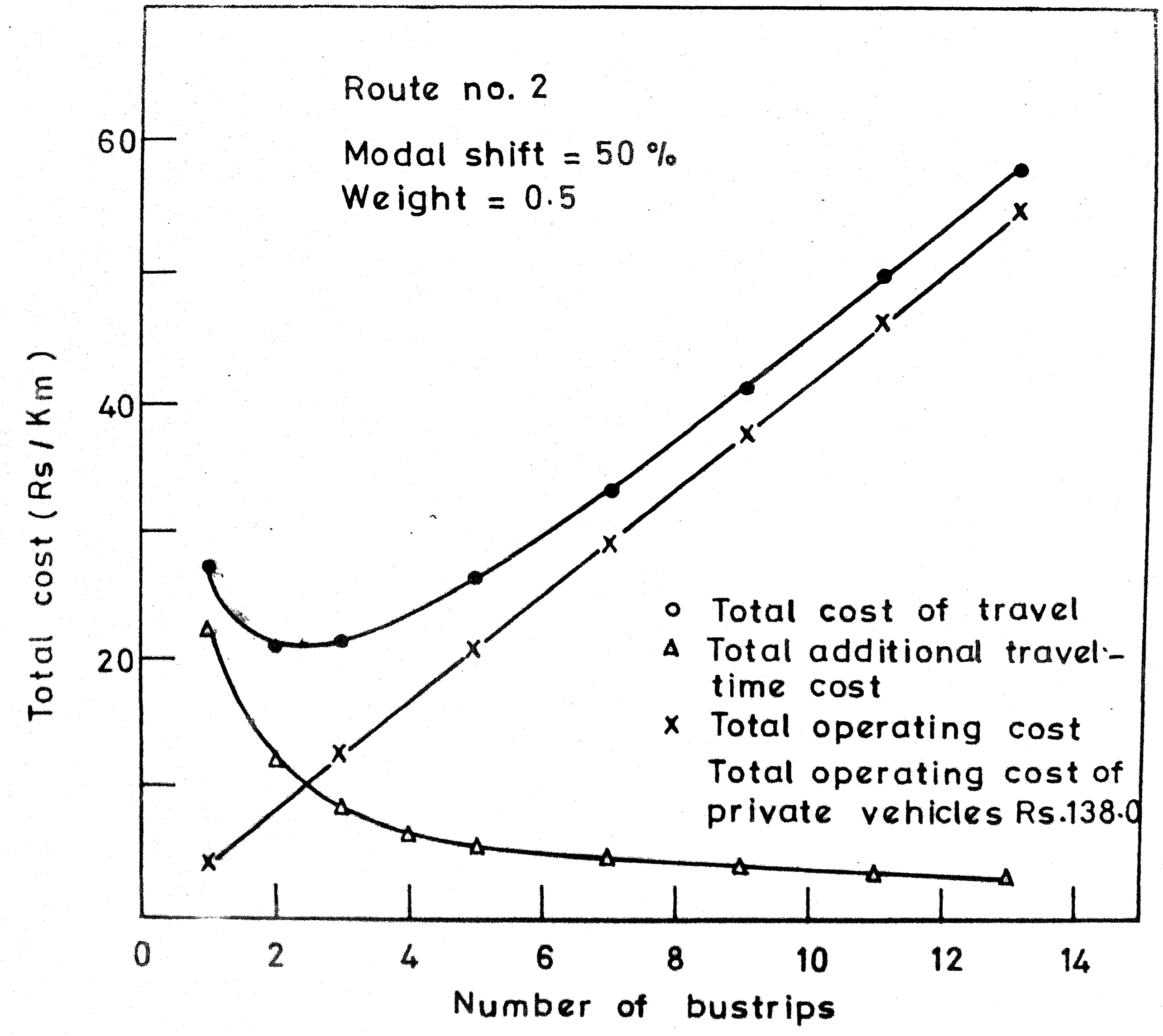

FIG. 4.16 TOTAL COST CURVES

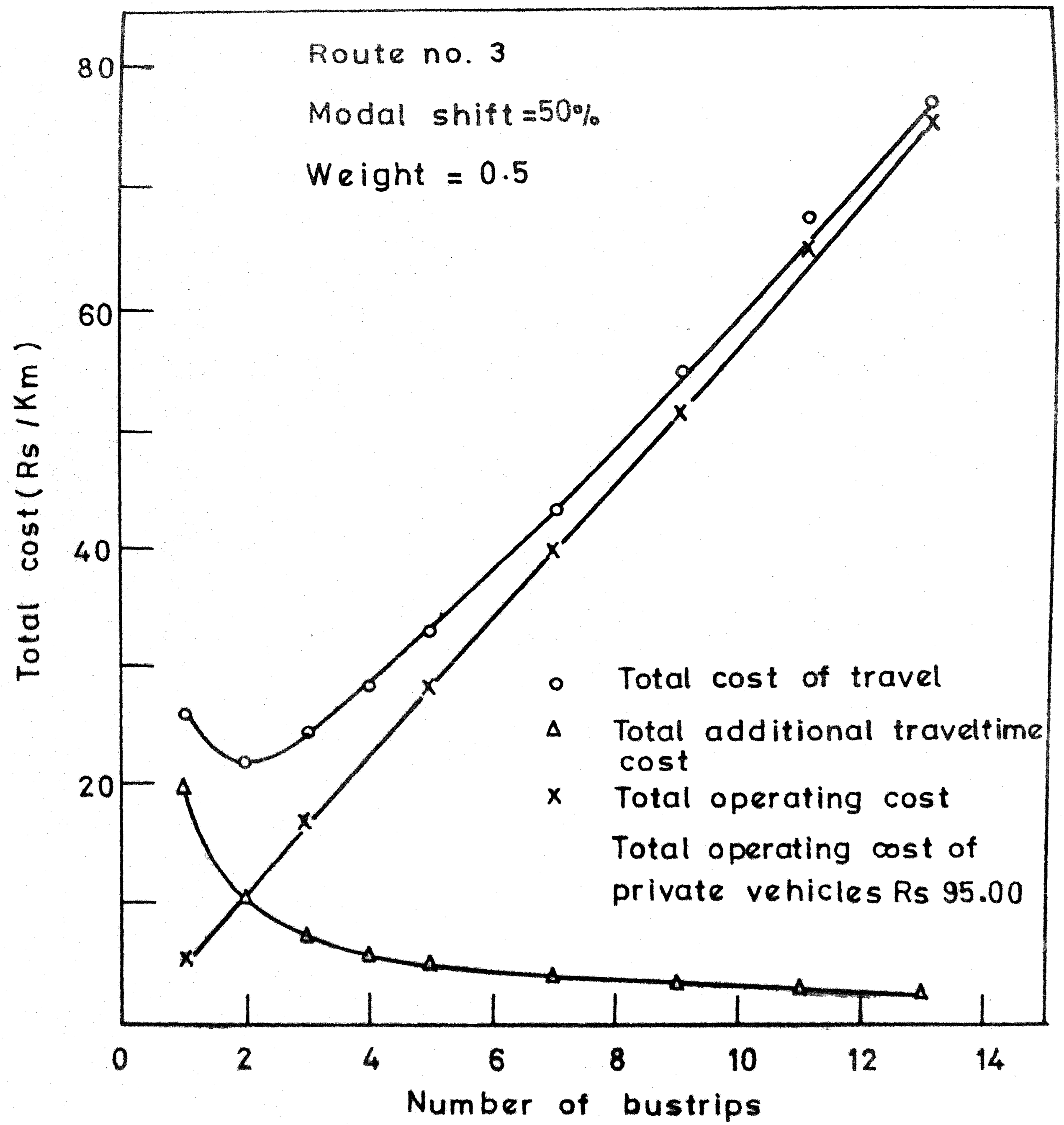

FIG. 4.17 TOTAL COST CURVES VARIATION

curves expressed in Rs. per km. The variations of these costs for all the three routes are shown in Fig. 4.15-17 and the effect of the parameters under each head follows :

(i) Total Operating Cost :

This cost increases with the number of bustrips for a given percentage of modal shift as the capacity utilisation reduces.But with higher percentages of modal shift, the total operating cost reduces due to the increase in the number of passengers. This cost, being a function of the load, is not affected by the weight for value of time.

(ii) Total Additional Travel Time Cost :

This cost is a function of time only and hence is affected by the weight for value of time. With increase in the number of bustrips the waiting time and consequently the additional travel time cost reduces. With an increase in the weight for the value of time the cost of the additional travel time is also increased.

(iii) Total Costs :

Total cost is a function of both the percentage of modal shift and the weight for value of time. For a given percentage of modal shift the total cost increases with the weights for value of time. But for an increase in modal shift for a given weight of value of time, the total

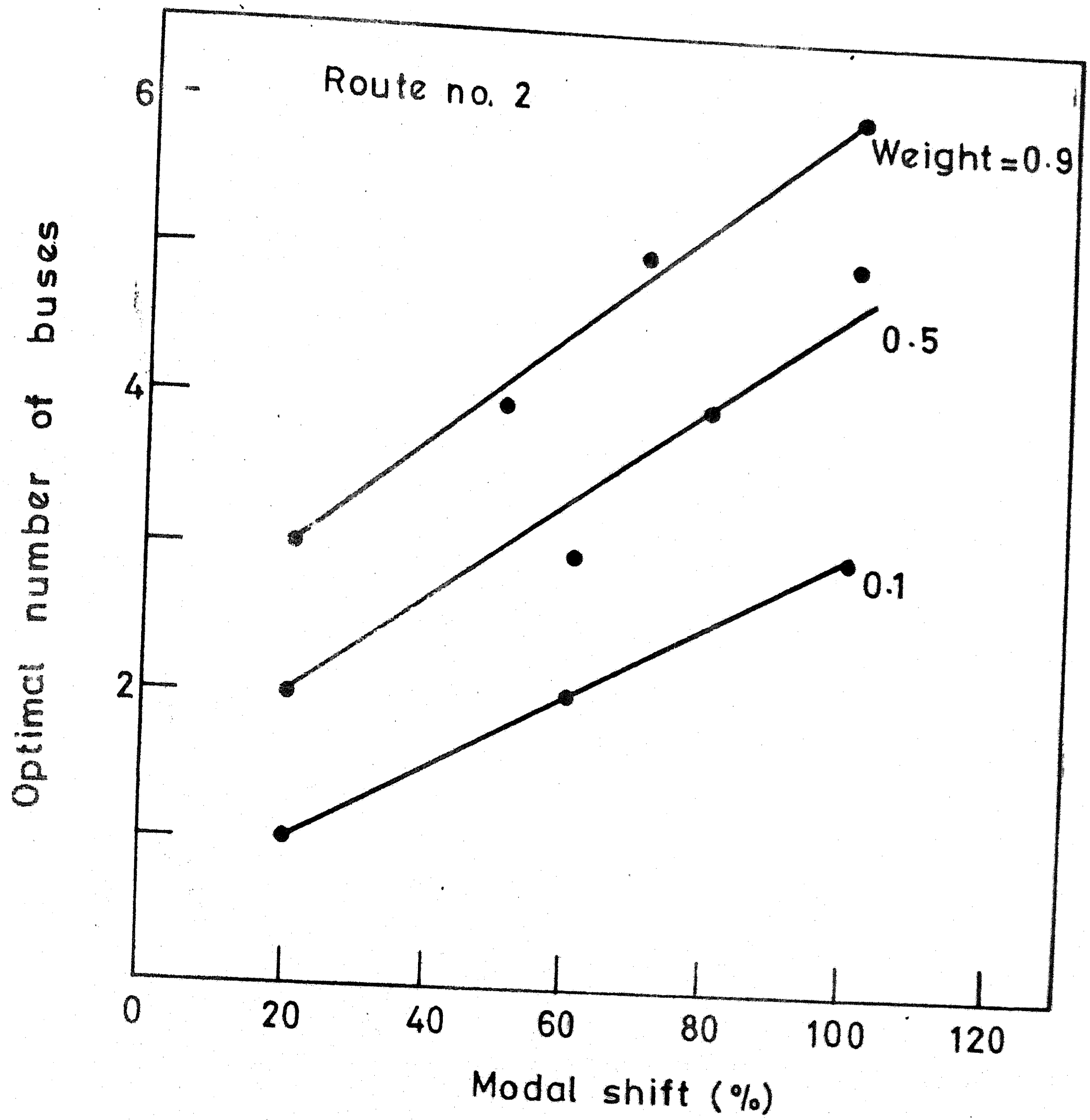

FIG. 4.18 VARIATION OF OPTIMAL NUMBER OF BUSES WITH MODAL SHIFT AND WEIGHT FOR VALUE OF TIME

TABLE 4.10. OPTIMAL NUMBER OF BUSTRIPS FOR DIFFERENT LEVELS OF MODAL SHIFT AND WEIGHT FOR VALUE OF TIME.

WEIGHT	MODAL SHIFT	MAXIMUM DEMAND ON EACH ROUTE ROUTE # 1	ROUTE # 2	ROUTE # 3
		842	523	364
0.1	20	1	1	1
	50	2	1	1
	100	2	2	1
0.5	20	2	2	1
	50	4	2	2
	100	5	3	3
0.9	20	3	2	2
	50	4	3	3
	100	6	4	4

cost reduces due to the reduction in the total operating costs. The total cost curve is used to dermine the optimal number of bustrips at different levels of modal shift and weight for value of time.

4.10 Optimal Number of Bustrips

For a given percentage of modal shift and weight for value of time, the optimal number of bustrips corresponds to the minimum total cost of travel. Thus the optimal number of bustrips for different level of these parameters is determined. Table 4.10 shows such bustrips for modal shift of 20, 50, and 100% and weights of 0.1, 0.5 and 0.9. It is observed that the optimal number increases with modal shift and weights for time as well. For higher passenger demands, the operating cost reduces but for higher weights for time the additionaltravel time cost increases thus shifting the optimal point towards the right. This behaviour is also shown in Fig. 4.18.

It is noted in Table 4.10 that the optimal number of bustrips obtained from the cost criteria does not cater to the entire demand on a given route. Since the optimal number of bustrips is determined for a trade-off between the operating cost and passengers' additional travel time cost, the total demand can not be satisfied. Hence a compromise should be struck to operate the number of bustrips

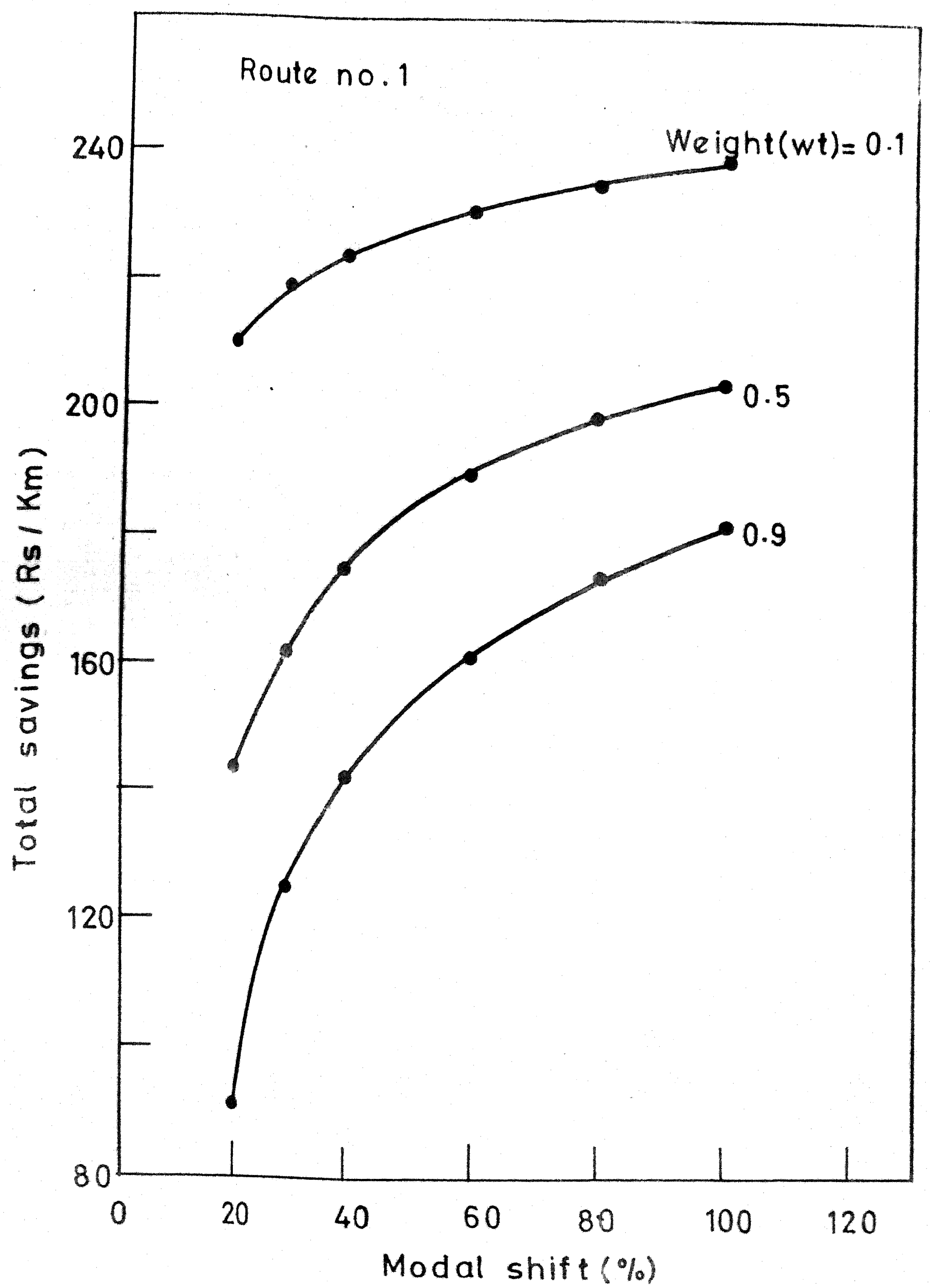

FIG. 4.19 VARIATION OE SAVINGS WITH PERCENTAGE MODAL S IIFT AND WEI IT FOR VALUE OF TIME

TABLE 4.11. DECREASE IN SAVINGS AT UNIT LOAD FACTOR.

WT	MS %	TOTAL DEMAND	OPTN	ALF	COST(Rs/Km)			REQN	ALF	COST(Rs/Km)		
					OC	TC	SAV			OC	TC	SAV
0.1	20	168	1	2.80	5.35	10.20	210.20	3	0.94	16.47	18.29	169.75
	50	421	2	3.51	10.67	17.12	226.95	7	1.00	37.59	39.93	181.24
	100	842	2	7.016	10.67	23.57	237.63	14	1.00	69.17	72.44	188.76
0.5	20	168	2	1.4	10.67	23.55	143.34	3	0.94	16.47	25.57	133.33
	50	421	4	1.75	21.35	39.37	182.73	7	1.00	37.59	49.52	162.16
	100	842	5	2.80	26.81	57.17	204.03	14	1.00	69.17	81.13	180.07
0.9	20	168	3	0.93	16.97	32.86	96.90	3	0.94	16.47	32.86	96.90
	50	421	4	1.75	21.35	53.79	153.02	7	1.00	37.59	59.06	143.07
	100	842	6	2.33	32.02	79.85	181.35	14	1.00	69.17	98.61	162.54

WT := Weight for value of time.
MS := Modal Shift.
ALF := Average Link Load Factor.
OC := Total Operating Cost.
TC := Total Travel Cost.
SAV :=Total Savings.
OPTN := Optimum Number of Bustrips.
REQN := Number of Bustrips required to meet entire demand.

such that it is profitable to the operator also and this is possible only at the expense of the demand. However, this is true in cases where the destination is same for all the passengers. In such cases, the passengers board the bus along the route but are destined for the same zone. Hence the occupancy ratio is comparatively low in the initial links of the route.

However the entire demand can be met at the expense of the savings. Referring to Table 4.11, if the required number of bustrips is plied, the total operating cost and the total cost also increase, thus reducing the savings. It is also noticed that with higher weights the savings increase but they are reduced if the required number of bustrips is provided.

4.10.1 Effect on Savings

The savings on a given route is a function of the total cost only as the operating cost of private vehicle is constant (Equation 4.20). Fig. 4.19 shows the variation of savings plotted for the optimal number of bustrips at different levels of modal shift and weights of time. For a given weight of time the savings increase with modal shift due to reduction in operating costs. But for a given modal shift the savings reduce with increase in weight of time as the latter increases the cost of additional travel

time. Thus, for higher values of modal shift and weights of time, the total savings are reduced.

4.11 Criteria for Implementation

The cost curves criteria give the maximum savings for a combination of the modal shift and the weight for time. The savings obtained for different levels of these parameters can act as guidelines for the implementation of the bus system . The total demand of passengers can also be satisfied at the expense of savings which finally result in plying the buses at a lower load factor.

However, the overall savings resulting from implementing the system is of importance. A goal for any such energy conservation program is to institute means to effect the conservation of the energy without limiting the mobility of the population or lowering the quality of the transportation system.

4.11.1 Energy Efficiency Criteria

The methodology can better be understood by considering the energy efficiency of the transit system. The efficiency of a vehicle cannot be assessed without knowing the environment in which it operates, as the relative ranking of modes in terms of energy efficiency could change as the environment changes. The energy efficiency of transport

system is defined in terms of the passenger-Km. per litre of fuel used. This efficiency carries with it a built in implication of loadfactor so that a mode is penalized if it carries lesser load.

Some insights into the potentialities for energy savings in urban home-to-work trips can be gained by studying this energy efficiency and the modal shift factor.

Let C = capacity of the bus

F_2, F_4 = fractions of travellers using two and four-wheelers respectively.

K_B, K_2, K_4 = average triplength made by bus, two and four-wheelers respectively.

L_B, L_2, L_4 = Total fuel consumed by bus, two and four-wheelers respectively.

P_B, P_2, P_4 = Total passengers per rush hour trip on bus, two and four-wheelers respectively.

n_B, n_2, n_4 = Efficiency of bus, two and four-wheelers respectively.

Assuming that there is a 100% modal shift,

Let $F_2 = P_2/P_B$ and $F_4 = P_4/P_B$

Then $P_B = F_2 . P_B + F_4 . P_B$

Efficiency of bus n_B

=(bus capacity * loadfactor * triplength)/ fuel consumed.

$n_B = 60 * 0.6 * 6 = 216$ pass Km/Litre

Similarly for two and four-wheelers

$n_2 = 1* 35 = 35$ pass-Km/Litre (Capacity = 1)

$n_4 = 2* 13 = 26$ pass-Km/Litre (Capacity = 2)

Then the fuel consumption can be obtained from

$$L_B = P_B . K_B / n_B \quad (4.21a)$$

$$L_2 = P_2 . K_2/n_2 \quad (4.21b)$$

$$L_4 = P_4 K_4/n_B \quad (4.21c)$$

For route No. 1;

Routelength $K_B = 17.25$ Km.

Total four-wheelers passengers = 84

Total two-wheelers passengers = 758

From equation 4.21a-c

$L_B = (84+758)* 17.25/216 \quad = 67.2$ litres

$L_2 = 758* 9.6/35 \quad = 208$ litres

$L_4 = 84 * 10.6/26 \quad = 34.2$ litres

Thus the total petrol consumed by two and four-wheelers in making home-to-workplace trips is 242.2 litres and the amount of diesel consumed is 67.2 litres.

Thus an idea of the magnitude of the savings can be had, based on this criteria.

TABLE 4.12. TOTAL BUS-Kms. FOR DIFFERENT MODAL SHIFT AND WEIGHT FOR VALUE OF TIME.

WEIGHTAGE WT	MODAL SHIFT in(%)	LENGTH OF ROUTES 1	2	3	TOTAL BUSKms
		17.25Kms	11.5Kms	14.5Kms	
0.1	20	17.25	11.50	14.50	43.25
	50	34.50	11.50	14.50	60.50
	100	34.50	23.00	14.50	72.00
0.5	20	34.50	23.00	14.50	72.00
	50	69.00	23.00	29.00	121.00
	100	86.25	34.50	43.50	164.25
0.9	20	41.75	23.00	29.00	93.75
	50	69.00	34.50	43.50	147.00
	100	73.50	43.00	58.00	174.50

TABLE 4.13. TOTAL SAVINGS FOR DIFFERENT LEVELS OF MODAL SHIFT AND WEIGHTAGE FOR VALUE OF TIME.

MODAL SHIFT (%)	WEIGHTAGE (WT)	SAVINGS ON EACH ROUTE (Rs/Km) 1	2	3	TOTAL SAVINGS (Rs/Km)
20	0.1	210.20	116.92	66.93	394.05
	0.5	143.34	80.54	34.31	258.19
	0.9	96.90	60.99	7.39	165.28
50	0.1	226.95	129.53	84.04	440.52
	0.5	182.73	105.80	59.06	347.59
	0.9	152.62	90.62	42.04	286.28
100	0.1	237.63	133.77	89.74	461.14
	0.5	204.03	117.12	71.29	392.44
	0.9	181.35	105.59	59.14	346.08

4.12. An Overview of the Savings

The savings resulting from such a modal shift are of importance because of their value. However an estimate for the whole system at different levels of the modal shift and the weight for time is necessary to estimate the overall savings with a change in these parameters. Table 4.12 shows the total bus-kms for all the routes at different levels of modal shift and the weight for value of time. Table 4.13 shows the total savings resulting from all the three routes for different percentages of modal shift and weights for value of time. The maximum savings are obtained for the maximum modal shift and the minimum weight of time. An idea of the savings can be had by computing them in terms of Rs/month.

The savings shown in table 4.11 are for a unit kilometer. The total maximum savings possible are

461.14 * 43.25 * 26 * 2 = Rs. 10,30796 - 00.

-Considering 26 days in a month and 2 trips a day. Similarly the minimum savings possible are

165.28 x 93.25 * 26 * 2 = Rs. 3, 71714-00

On implementation of such a system it is likely that there will not be a higher percentage of modal shift in the initial stage. Hence the provision of bustrips based on the minimum total cost always results in an overall saving.

5. BUS SCHEDULING POLICIES

5.1 General

The frequency of service on a given route is usually based either on a formally adopted or unstated policy regarding the minimum level of service to be provided or on the frequency of service necessary to handle the loads. The former is known as the policy head way and is sometimes used in combination with the latter. Policy headway is more suitable for scheduling during the non-peak hours, the typical headway being every 60, 30 or 20 mins. (Koski, R.W., (1979)). During peak hours and on more heavily travelled lines, the frequency of service is more appropriately a function of passenger volume. Since additional drivers and buses are usually required to meet the peak hour demand anyway, a higher level of service during non-peak hours is also easily justified.

It is generally desirable to have any headways less frequent than every 10 mins. evenly divisible into 60. Departure times of any headway divisible into 60 repeat themselves each hour and then can more easily be remembered by the passengers. At headways more frequent than every 10 minutes, the idea of having headways which are divisible into 60, becomes unimportant since passengers are more likely to appear at the bus stop at random times.

In this study, the scheduling of buses has been done for the three routes designed to cater for the peak hour demand with a bus systems proposed for the city to industrial area movements.This scheduling for these buses is with the objective of minimising the waiting time of the passengers at each stop, on the basis of the despatching policy proposed by Newell G.F. (1971).

5.2 Minimum Wait Schedules

For a given number $(NBUS)_k$ of buses, they can be dispatched at any times from source to serve passengers along a route r. The arrival rate of passengers is a nonconstant of smooth function of time. The dispatch times t_d where $d = 1, \ldots (NBUS)_r$ can be chosen in such a way as to minimize the total waiting time of all passengers.

5.2.1. Formulation of Model

The model is proposed for a single route between a given origin and destination. The model is based on the following assumptions :

(i) The required number of buses are available at the origin.

(ii) The availability of buses at the origin $(ORG)_r$ on the r th route is independent of when previous buses may have been dispatched.

(iii) Passengers may board at certain points i along the route and alight at other points j.(for this study the passengers board at different stops and are destined for the industrial zone $(DEST)_r$ by r th route.).

(iv) The travel time of the bus is nearly independent of the loading and unloading at different stops.

(v) The demand is independent of the bus schedule.

The demand at any intermediate i th stop can be converted into an effective demand at the origin by transferring it with respect to time. Thus a trip at the i th station can be converted into an effective demand at time $t - (TT)_i$ where $(TT)_i$ is the time taken from the origin to that stop i.

It $P_{ij}(t)$ is the cumulative number of trips from i to j by time t, the effective cumulative demand at the origin for buses to depart by time t will be

$$P(t) = \sum_{i=1}^{N} \sum_{j=1}^{N-1} P_{ij}\,(t-(TT)_i) \quad (5.\ 1)$$

Where N = number of stops on the route.

5.2.1. Minimum Wait Time

Let the buses be dispatched at the origin $(ORIG)_k$ at times t_d, d = 1---- $(NBUS)_k$. If the number of buses is large,

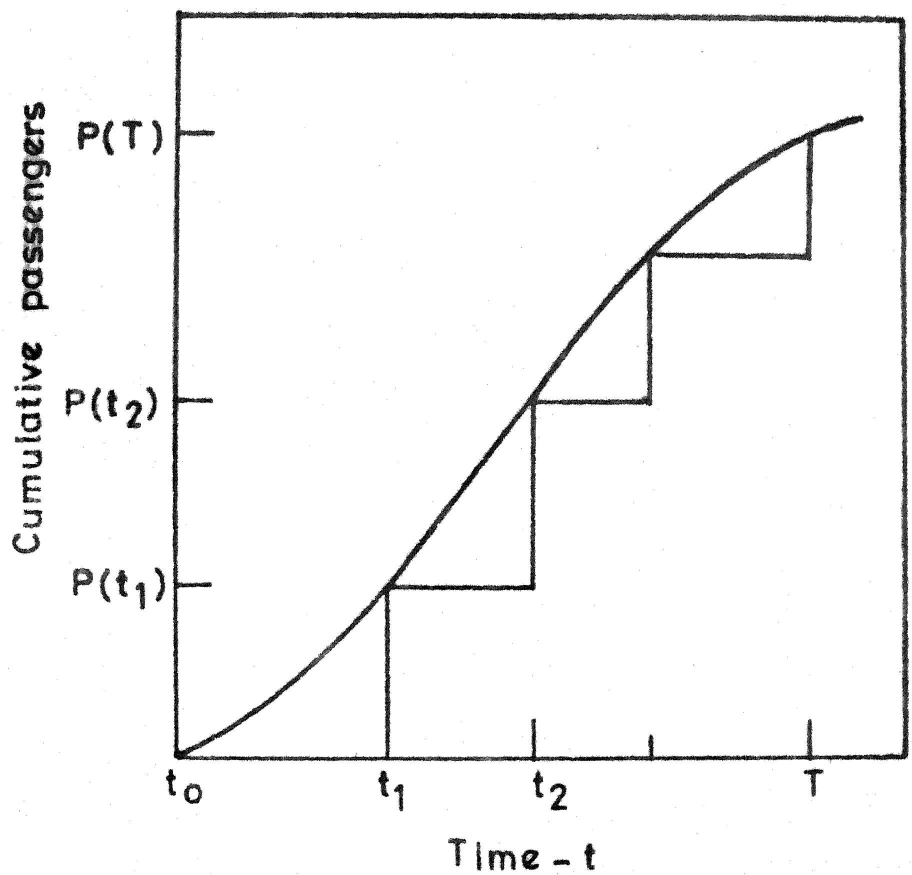

FIG. 5 1 VARIATION OF CUMULATIVE DEMAND WITH TIME

any number of passengers along the route can be served. Referring to figure 5.1, the totalwaiting time is represented by the sha: ed area.between the curve P(t) and the step function with heights $P(t_d)$ for $t_d = \leq t < t_{d+1}$. In such a case the passengers may arrive randomly at the stops since the frequency is high. On the other hand, at lower frequencies the passenger arrival is to co-ordinate with the bus schedules.

The waiting time of a passenger can be defined as the difference between the actual departure time and the desired departure time. Then the total waiting time W is the summation of all the waiting time for the passengers between two dispatching times

$$W = \sum_{d=0}^{NBUS - 1} \int_{t_d}^{t_{d+1}} (P(t) - P(t_d))\, dt \qquad (5.2)$$

This represents the sum of area of all the triangles. The time for d th dispatch is taken as to when demand $P(t_o)=0$ and $t_{NBUS} = T$ for a specified last despatch. The total waiting time can be minimised by differentiating (5.2) w.r.t. the dispatch time t_d and equating to zero.

Considering for the K th term

$$W = \sum_{d=0}^{k-2} \int_{t_d}^{t_{d+1}} (P(t)-P(t_d))\, dt + \int_{t_{k-1}}^{t_k} (P(t)-P(t_{k-1}))dt$$

$$+ \int_{t_k}^{t_{k+1}} (P(t) - P(t_k))\,dt + \sum_{d=k+1}^{n-1} \int_{t_d}^{t_{d+1}} (P(t)-P(t_d))\,dt$$

Assuming all t_d's to be constant except t_k, the two summation expressionswill not contribute anything to the derivative of W w.r.t. t_k as they are independent of t_k.

Hence

$$\frac{\partial W}{\partial t_k} = \frac{\partial}{\partial t_k} \left[\int_{t_{k-1}}^{t_k} (P(t)-P(t_{k-1}))\,dt \right.$$

$$\left. + \int_{t_k}^{t_{k+1}} (P(t) - P(t_k))\,dt \right]$$

using Leibnitz's formula, we obtain

$$\frac{\partial W}{\partial t_k} = \int_{t_{k-1}}^{t_k} \frac{\partial}{\partial t_k} (P(t)- P(t_{k-1}))\,dt + \frac{\partial t_k}{\partial t_k} (P(t_k)-P(t_{k-1}))$$

$$- \frac{\partial t_{k-1}}{\partial t_k} \underbrace{(P(t_{k-1}) - P(t_{k-1}))}_{\to 0} + \int_{t_k}^{t_{k+1}} \frac{\partial}{\partial t_k} (P(t)-P(t_k))\,dt$$

$$+ \frac{\partial t_{k+1}}{\partial t_k}(P(t_{k+1})-P(t_k)) - \frac{\partial t_k}{\partial t_k} \underbrace{(P(t_k) - P(t_k))}_{\to 0}$$

$$= P(t_k) - P(t_{k-1}) - \int_{t_k}^{t_{k+1}} \frac{\partial P(t_k')}{\partial t_k}\, dt$$

$$= P(t_k) - P(t_{k-1}) - f\,(t_k)\;(t_{k+1} - t_k)$$

where $f(t_k) = P'(t_k)$

substituting k=d

$$\frac{\partial W}{\partial t_d} = P(t_d) - P(t_{d-1}) - f\,(t_d)(t_{d+1} - t_d) \qquad (5\text{-}3)$$

Here $f(t_d)$ is the arrival rate of passengers

Equating (5.3) to zero we get the condition for the minimum

Than $t_{d+1} - t_d = (P(t_d) - P(t_{d-1}))/f(t_d)$ (5.4)

The properties of this solution can be studied by approximating $P\,(t_{d-1})$ or $P(t_{d+1})$ by the first few terms of the Taylors series expansion about t_d.

The general form of Taylor's series is

$$F\,(x-h) = F(x) - h\,F(x) + \frac{h^2}{2!}F''(x) - + \,..+(-1)^i \frac{h^i}{i!} F^{(i)}(x)$$

Since $P(t_{d-1}) \equiv P\,(t_d - (t_d - t_{d-1}))$

Expanding function t_d we get

$$P(t_{d-1}) \cong P(t_d) + P'(t_d)(t_{d-1} - t_d) + P''(t_d)(t_{d-1} - t_d)^2/2 \;+---$$

Considering the first two terms

$$P(t_{d-1}) \cong P(t_d) + P'(t_d)\;(t_{d-1} - t_d) \qquad (5.5)$$

Substituting (5.4) in (5.3) we get

$$t_{d+1} - t_d \cong t_d - t_{d-1} \tag{5.6}$$

Thus the adjacent time headways are equal. Hence if arrival rate is constant the optimal dispatch policy is to use constant headways. For large values of NBUS the neglecting of terms results in accumulation of error. Hence considering the first three terms

$$P(t_{d-1}) \cong P(t_d) + P'(t_d)\ (t_{d-1}-t_d) + P''(t_d)(t_{d-1}-t_d)^2/2$$

Substituting in (5.3)

$$(t_{d+1}-t_d) = (t_d - t_{d-1}) - (t_d-t_{d-1})^2\ P''(t_d)/2P'(t_d)$$

$$+ \text{ Other terms of order of } (t_d-t_{d-1})^2 \tag{5.7}$$

Substituting $d = d-1$

$$(t_d - t_{d-1}) = (t_{d-1}-t_{d-2}) \left[1- \frac{P''(t_d)}{2P'(t_d)}(t_{d-1}-t_{d-2})\right] \tag{5.8}$$

Substituting $(t_d - t_{d-1})$ in (5.6)

$$(t_{d+1} - t_d) = (t_{d-1} - t_{d-2}) \left[1 - \frac{P''(t_d)}{2P'(t_d)}\ (t_{d-1} - t_{d-2})\right] \times$$

$$\left[1 - (t_d-t_{d-1})\ \frac{P''(t_d)}{2P'(t_d)}\right]$$

$$t_{d+1} - t_d = (t_{d-1}-t_{d-2}) \prod_{l=d-1}^{d} \left[1- \frac{P''(t_l)}{2P'(t_l)}(t_l - t_{l-1})\right] \qquad (5.9)$$

Similarly puting $d = d-2$ in (5.7)

and substituting $(t_{d-1} - t_{d-2})$ so obtained in (5.8)

$$t_{d+1}- t_d = (t_{d-2}- t_{d-3}) \prod_{l=d-2}^{d} \left[1- \frac{P''(t_l)}{2P'(t_l)}(t_l-t_{l-1})\right].$$

Proceeding in a similar manner

$$t_{d+1}-t_d = (t_k-t_{k-1}) \prod_{l=k} \left[1- \frac{P''(t_l)}{2P'(t_l)}(t_l-t_{l-1})\right] \qquad (5.10)$$

The terms under the product sign can be approximated by an exponential functions.

Since $\exp(-x) = 1-x + \frac{x^2}{2!} + \frac{x^3}{3!} + \text{--} -$

for small values of x it can be approximated by $\exp(-x)$

$$\text{i.e. } \exp(-x) = 1-x$$

Similarly (5.10) can be approximated as

$$(t_{d+1}- t_d) = (t_k-t_{k-1}) \prod_{l=k}^{d} \exp\left[- \frac{P''(t_l)}{2P'(t_l)}(t_l-t_{l-1})\right]$$

or

$$(t_{d+1}- t_d) = (t_k- t_{k-1}) \exp\left[- \sum_{l=k}^{d} \frac{P''(t_l)}{2P'(t_l)}(t_l-t_{l-1})\right]$$

(as $e^x . e^y$ can be written as e^{x+y})

For sufficiently small intervals of $(t_l - t_{l-1})$ the summation can be approximated by an integral and written as

$$t_{d+1} - t_d = (t_k - t_{k-1}) \exp \left[- \int_{t_{k-1}}^{t_d} \frac{P''(t)}{2P'(t)} \, dt \right]$$

Or $$t_{d+1} - t_d = (t_k - t_{k-1}) \exp \left[- \tfrac{1}{2} \int_{t_{k-1}}^{t_d} \frac{f'(t)}{f(t)} \, dt \right]$$

$$= (t_k - t_{k-1}) \exp \left[-\tfrac{1}{2} \ln \left\{ \frac{f(t_d)}{f(t_{k-1})} \right\} \right]$$

$$= (t_k - t_{k-1}) \exp \left[\ln \left\{ \left(\frac{f(t_d)}{f(t_{k-1})} \right)^{-\frac{1}{2}} \right\} \right]$$

$$= (t_k - t_{k-1}) \left[\frac{f(t_{k-1})}{f(t_d)} \right]^{\frac{1}{2}}$$

Thus

$$(t_{d+1} - t_d) \, f^{\frac{1}{2}}(t_d) = (t_k - t_{k-1}) \, f^{\frac{1}{2}}(t_{k-1})$$

This shows that $(t_{d+1} - t_d) \, f^{\frac{1}{2}}(t_d)$ is independent of d and so can be written as

$$(t_{d+1} - t_d) \, f^{\frac{1}{2}}(t_d) = \text{constant} \qquad (5.11)$$

Writing Taylor's series for $P(t_{d+1})$ about $P(t_d)$

$$P(t_{d+1}) = P(t_d) + P'(t_d) . (t_{d+1} - t_d) + \text{-----}$$

Neglecting the higher order terms

$$P(t_{d+1}) - P(t_d) = f(t_d) \;.\; (t_{d+1} - t_d)$$

$$\text{OR} \quad f(t_d) = \frac{P(t_{d+1}) - P(t_d)}{(t_{d+1} - t_d)}$$

Substituting into (5.9)

$$(t_{d+1} - t_d)^{\frac{1}{2}} \left[P(t_{d+1}) - P(t_d)\right]^{\frac{1}{2}} = \text{Constant} \quad (5.12$$

Equation (5.11) can be written as

$$f^{\frac{1}{2}}(t_d) = \frac{C}{(t_{d+1} \; t_d)}$$ where 'C' is a constant.

Thus the arrival rate of the buses (which is the inverse of the headways) is proportional to the square roof of the arrival rate of the passengers.

5.2.2. Optimal Headways

The optimal headways space the busses such that the total waiting time is minimized. Since the optimal headways are a function of the arrival rate of passengers, the dispatch schedule depends on the variations of passenger demand with time. For a constant arrival rate, the optimal policy would be to have constant headways.

In case of non-linear variation of the passenger demand with time the optimal headways can be determined as follows :

Let $B = N\,(t_{d+1} - t_d)\, f^{\frac{1}{2}}(t_d)$ (5.12)

where B is a constant according to (5.10)

The number of vehicles dispatched per unit time from (5.12) is

$$\frac{1}{t_{d+1} - t_d} = \frac{N.\, f^{\frac{1}{2}}(t_d)}{B} \tag{5.13}$$

The total number of dispatches are between the given times t_1 and T

$$N \cong \frac{1}{B} N \int_{t_0}^{T} f^{\frac{1}{2}}(t)\,dt \tag{5.14}$$

or

$$B \cong \int_{t_0}^{T} f^{\frac{1}{2}}(t)\,dt$$

Substituting expression for B in (5.13) the headways at time t_d are

$$t_{d+1} - t_d = \frac{\int_{t_0}^{T} f^{\frac{1}{2}}(t)\,dt}{N\, f^{\frac{1}{2}}(t_d)} \tag{5.15}$$

5.3 Implementation of the model

The dispatching of buses is done on the basis of the optimal headways obtained from the model for the optimal number of buses from the minimum cost criteria. The dispatching is done such that the total waiting time of the passengers is minimized.

5.3.1. Generation of Arrival Times

The model is based on the concept that, the intermediate demands are transferred to the origin and the effective demand thus obtained at the origin is utilized for scheduling the dispatches. Hence it is necessary that the arrival times of all the passengers at different stops be known. Since the data was not available for the arrival times of the passengers it was assumed that the arrival gaps follow an exponential distribution.

Based on this assumption arrival gaps were generated for each passenger arriving at a particular stop enroute, by using the SIMULA random generator NEGEXP(A,U) which gives exponentially distributed arrival gaps. Here A is the inverse of the arrival rate and U is the initial seed for the generator. The arrival times at the origin of all the passengers along the route are obtained as follows :

$$(ARRGAP)_{pi} = NEGEXP(A, U)$$

$$(ARRTIME)_{pi} = (ARRTIME)_{p-1} + (ARRGAP)_{p}$$

$$(ORARTIME)_{pi} = (ARRTIME)_{pi} - (TRTIME)_{oi}$$

where

$(ARRGAP)_{pi}$ = arrival gap for the p th passenger at i th stop.

$(ARRTIME)_{pi}$ = arrival time for the p th passenger at the i th stop.

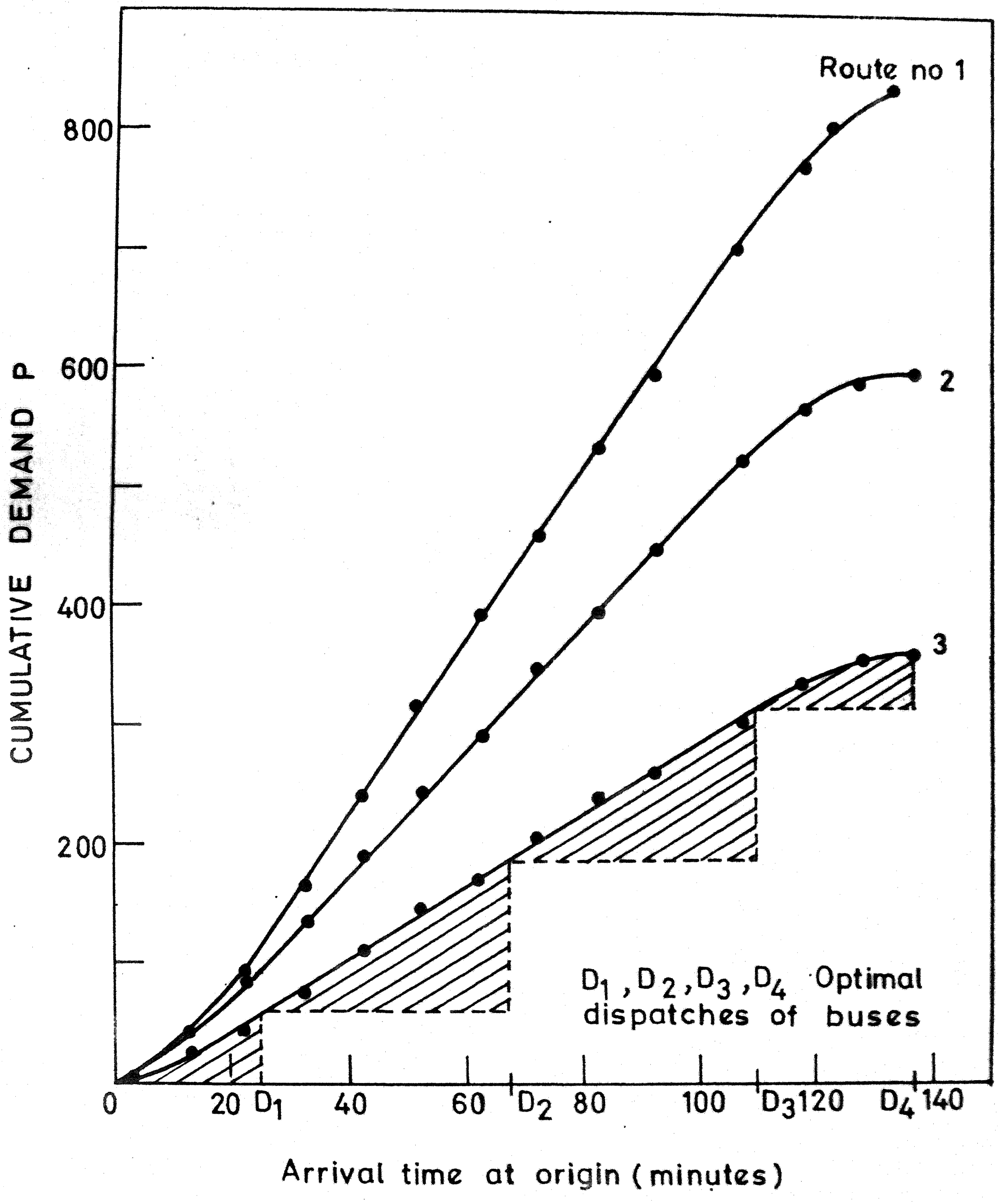

FIG.5.2 VARIATION OF CUMULATIVE DEMAND WITH ARRIVAL TIME

TABLE 5.1. CUMULATIVE DISTRIBUTION FOR DEMAND ON ROUTE NO. 1.

S.NO.	CLASS INTERVAL	MIDPOINT	FREQUENCY	CUM.FREQUENCY
1	0.00- 4.99	2.50	2	2
2	5.00- 9.99	7.50	14	16
3	10.00- 14.99	12.50	24	40
4	15.00- 19.99	17.50	25	65
5	20.00- 24.99	22.50	31	96
6	25.00- 29.99	27.50	33	129
7	30.00- 34.99	32.50	39	168
8	35.00- 39.99	37.50	44	212
9	40.00- 44.99	42.50	31	243
10	45.00- 49.99	47.50	41	284
11	50.00- 54.99	52.50	38	322
12	55.00- 59.99	57.50	37	359
13	60.00- 64.99	62.50	37	396
14	65.00- 69.99	67.50	37	433
15	70.00- 74.99	72.50	31	464
16	75.00- 79.99	77.50	31	495
17	80.00- 84.99	82.50	35	530
18	85.00- 89.99	87.50	36	566
19	90.00- 94.99	92.50	31	597
20	95.00- 99.99	97.50	49	646
21	100.00-104.99	102.50	41	687
22	105.00-109.99	107.50	24	711
23	110.00-114.99	112.50	25	736
24	115.00-119.99	117.50	35	771
25	120.00-124.99	122.50	34	805
26	125.00-129.99	127.50	23	828
27	130.00-134.99	132.50	[illegible]	[illegible]

TABLE 5.2. CUMULATIVE DISTRIBUTION FOR DEMAND ON ROUTE NO. 2.

S.No.	CLASS INTERVAL	MIDPOINT	FREQUENCY	CUM.FREQUENCY
1	0.00- 4.99	2.50	7	7
2	5.00- 9.99	7.50	12	19
3	10.00- 14.99	12.50	15	34
4	15.00- 19.99	17.50	21	55
5	20.00- 24.99	22.50	31	86
6	25.00- 29.99	27.50	31	117
7	30.00- 34.99	32.50	26	143
8	35.00- 39.99	37.50	19	162
9	40.00- 44.99	42.50	32	194
10	45.00- 49.99	47.50	24	218
11	50.00- 54.99	52.50	31	249
12	55.00- 59.99	57.50	24	273
13	60.00- 64.99	62.50	28	301
14	65.00- 69.99	67.50	24	325
15	70.00- 74.99	72.50	29	354
16	75.00- 79.99	77.50	27	381
17	80.00- 84.99	82.50	13	394
18	85.00- 89.99	87.50	31	425
19	90.00- 94.99	92.50	23	448
20	95.00- 99.99	97.50	28	476
21	100.00-104.99	102.50	30	506
22	105.00-109.99	107.50	20	526
23	110.00-114.99	112.50	25	551
24	115.00-119.99	117.50	15	566
25	120.00-124.99	122.50	12	578
26	125.00-129.99	127.50	8	586
27	130.00-134.99	132.50	2	588

TABLE 5.3. CUMULATIVE DISTRIBUTION FOR DEMAND ON ROUTE NO. 3.

S.No.	CLASS INTERVAL	MIDPOINT	FREQUENCY	CUM.FREQUENCY
1	0.00- 4.99	2.50	5	5
2	5.00- 9.99	7.50	13	18
3	10.00- 14.99	12.50	10	28
4	15.00- 19.99	17.50	11	39
5	20.00- 24.99	22.50	9	48
6	25.00- 29.99	27.50	11	59
7	30.00- 34.99	32.50	17	76
8	35.00- 39.99	37.50	18	94
9	40.00- 44.99	42.50	16	110
10	45.00- 49.99	47.50	17	127
11	50.00- 54.99	52.50	17	144
12	55.00- 59.99	57.50	10	154
13	60.00- 64.99	62.50	19	173
14	65.00- 69.99	67.50	13	186
15	70.00- 74.99	72.50	20	206
16	75.00- 79.99	77.50	14	220
17	80.00- 84.99	82.50	15	235
18	85.00- 89.99	87.50	17	252
19	90.00- 94.99	92.50	7	259
20	95.00- 99.99	97.50	15	274
21	100.00-104.99	102.50	15	289
22	105.00-109.99	107.50	12	301
23	110.00-114.99	112.50	16	317
24	115.00-119.99	117.50	13	330
25	120.00-124.99	122.50	14	344
26	125.00-129.99	127.50	9	353
27	130.00-134.99	132.50	5	358
28	135.00-139.99	137.50	0	358

$(ORARTIME)_p$ = arrival time of the p th passenger at the origin.

$(TRTIME)_{oi}$ = Travel time from i th stop to origin o.

For the first passenger the arrival time is equal to the arrival gap. Thus the arrival times of all the passengers were generated and transferred to the origin for all the three routes for a period of 120 minutes. Since the curve for the passenger demand has to be known to determine the optimal headways of the buses, a frequency table was formed with a class interval of 5.0 minutes and the cumulative passenger demand P was determined. Tables 5.1 - 5.3 show the cumulative frequency for routes No. 1,2 and 3 respectively. The cumulative frequency is plotted against the time to observe the arrival rate of passengers Fig. 5.2 shows the variation of passenger demand with time for all the three routes.

5.3.2. Dispatching Schedules

It is observed in Fig. 5.2 that the cumulative demand varies parabolically in the initial stage say upto 25 minutes and then is linear till 110 minutes. For arrival times greater than 110 minutes the variation is again parabolic in nature. The slope at any point on this curve gives the arrival rate of passengers at that corresponding time. Since the arrival rate is low in the initial stages

TABLE 5.4. DISPATCH AND TOTAL WAITING TIMES ON ALL ROUTES.

BUSTRIP NO.	DISPATCH TIME (mins.)	TOTAL WAITING TIME (mins.)
FOR ROUTE NO. 1 :-		
1	25	1500
2	45	1400
3	70	2310
4	90	1550
5	115	2000
6	135	712
FOR ROUTE NO. 2 :-		
1	30	1800
2	70	4000
3	105	3325
4	135	1710
FOR ROUTE NO. 3 :-		
1	25	1750
2	67	2968
3	110	2968
4	135	1215

MODAL SHIFT = 100% , WEIGHT OF TIME = 0.9 .

the exponential nature is distinctly observed during that period. Later, with an increase in number of passengers, the arrival times are so closely spaced that the curve is approximated as a linear one. During the end of the scheduling period the arrival rate reduces and hence the curve is parabolic in nature.

Thus it is obvious from the curve that it would be desirable to dispatch the first bus at the begining of the constant slope since the arrival rate is comparatively less. Also Equation (5.6) shows that, the optimal dispatch policy for a constant arrival rate is to have equal headways. Hence for the linear part of the curve the headways will be equal. Similarly it is desirable to have the last dispatch at the end of constant arrival rate.

The schedules for all the three routes have been computed and are as shown in Table 5.4. The sum of the shaded triangles gives the total waiting time of the passengers and is the minimum waiting time.

If the cumulative demand curve is nonlinear in nature the optimal headways can be computed by using equation (5.15). Thus for a given number of buses on a route the optimal headways and the actual dispatch times can be worked out on the basis of this model.

6. SUMMARY, CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

6.1 Summary

The provision of an improved bus system may cause a modal shift of the private vehicle users to the bus system and also helps in reducing the cost of travel, fuel consumption and the congestion on the roads.

Nagpur city was chosen for this case study as it represents a majority of the cities in India. Work trips made to the industrial area by cars, scooters, motorcyle and other four-wheelers were analysed to determine the trip origins, travel time and the fuel consumption. Based on this observed travel pattern three different routes were designed to meet the existing travel demand.

The traffic demand on various routes was estimated for varying percentages of modal shift for two and four-wheelers. Experimental runs were made with these traffic demands and the weights associated with the value of additional travel times to find the optimal number of bustrips to be performed on each route based on minimum travel cost criterion.

The percentage of modal shift and the weights for value of time was varied and their effect on the various costs was studied. The savings resulting from implementation

of such a bus system were also computed at different levels of modal shift and weights for value of time.

The scheduling of bustrips was also done by developing a mathematical model that minimizes the waiting time of passengers.

6.2 Conclusions

A study was conducted for the city of Nagpur to analyse the savings in fuel consumption resulting from a modal shift of private vehicle owners to thepublic transit system. Based on this study the following conclusions were drawn.

In several medium-sized cities in our country, there has been a recent growth of industries as a result of which the number of work trips from the various parts of the city to such industrial zones has increased considerably.

In the absence of an adequate public transit system these trips are generally made by private motor vehicles from different parts of the city. This leads to an increase in the fuel consumption and the operating cost to the users as well. In such instances, the provision of an improved bus system will cause a modal shift of the private vehicle users to the bus system and also helps in reducing the cost of travel, fuel consumption and the congestion on the roads.

The demand for worktrips is concentrated between certain periods of the day. The routing and scheduling of bus lines to meet this demand, should be optimally designed, both from the users ' and the operators' points of view.

In view of the necessity for such a system, a procedure has been defined to design the optimal bus lines based on the trip distribution array. It also specifies the requirements of average link load factor, occupancy ratio, length of routes, passenger flow etc. Three new bus lines conforming to these requirements were designed to serve the trip makers of the industrial area.

The number of bustrips to be made on a route during the peak period depends upon the traffic demand, its distribution for various zones and the desired level of service viz. waiting time, average link load factor occupancy ratio. For a given demand, increase in number of bustrips reduces the waiting time, average link load factor and occupancy ratio but increases the operating cost of vehicles. The optimal number of bustrips on a route can be designed based on the minimum unit total cost (i.e. cost perpassenger per Km.).

The traffic demand on various routes was estimated for varying percentages of modal shift for two-wheelers and four-wheelers. Experimental runs were made with these

traffic demands and the weights associated with the value of additional travel time to find the optimal number of bustrips to be performed on each route based on minimum travel cost criterion. The overall saving in terms of cost and fuel have been worked out for different combinations. The maximum and minimum savings, corresponding to the highest and lowest percentage of modal shift and minimum and maximum weights, were computed as Rs. 10,30796.00 and Rs. 3,7171.00 per month respectively.

The number of bustrips on a route obtained from the minimum cost criteria do not satisfy the entire demand, but this passenger demand constraint can be met by plying the buses so that the load factor is near unity thus raising the operating costs and reducing the savings. It is noticed that even at this operating cost the savings are appreciable.

A dispatching policy for these optimal number of bus trips is worked out by developing a mathematical model such that the total waiting time is minimised.

6.3 Suggestions for Future Study

This study has been done on a smaller scale and based on several assumptions, but the system can be understood better by including some more parameters.

(i) This case study has been restricted to the industrial zone only, but can be done on a larger scale for other

zones which attract worktrips.

(ii) In this study the vehicles have been categorised as two and four-wheelers, but it is preferable to categorize the two wheelers into scooters, motorcycles and mopeds as there is a marked difference in their fuel consumption.

(iii) An average income has been assumed for the two and four-wheeler owners, but different slabs of income can be considered for each type of vehicle owner and their sensitivity be studied.

(iv) The waiting time is assumed as one half the headway. Based on the arrival gap distribution, waiting time distribution can be used for better results.

(v) Since the energy consumption is related to the landuse pattern appropriate can be models implemented to study its effect.

APPENDIX A

DEPARTMENT OF CIVIL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY, KANPUR

Dear Sir/Madam,

I survey is being conducted to analyse the fuel consumption of different vehicles. The data required is being collected through this questionnaire. Kindly fill in the necessary information.

FUEL CONSUMPTION QUESTIONNAIRE

1. Name (Optional) ------------------------------

2. Tick the type of vehicle being used :

    i. Scooter ( ) ----------
    ii. Moped ( ) ----------
    iii. Motor-cycle ( )
    iv. Car ( )
    v. Jeep ( )
    vi. Other vehicles (name)

3. Name the make of the vehicle ____________________

4. Registration number ____________________

5. Locality in which residence is situated ________________

6. Locality in which office/factory is located ________________

7. Approximate distance between office/factory and residence ____________ kms/miles.

8. Approximate time taken by own vehicle ___________ Mins/hrs.

9. Number of trips made from residence to office/factory per day. ______________

10. Average fuel consumption per month for these trips ______________ Litres

OR Rs. ______________

11. How often own vehicle is used.
Tick one of the following :
(i) Always ____________
(ii) 75=100 % ____________
(iii) 50-75 % ____________
(iv) Less than 50%

12. Do you travel by any other mode : YES/N

If Yes, (a) Tick the modes used: i. Buses
ii. Taxi
iii. Auto-rikshaw
iv. Any other mode

(b) Approximate time spent to get a Taxi/Auto/Bus while travelling from residence to office ___ mins.

(c) Approximate time spent to get a Taxi/Auto/Bus while travelling from office to residence _____ min

(d) Approximate time spent to reach Taxi/Auto/Bus stand from residence __________ mins.

(e) Approximate time spent to reach Taxi/Auto/Bus stand from Office/Factory ___________ mins.

(f) Approximate time taken by

(i) Taxi _________ mins.
(ii) Auto _________ mins.
(iii) Bus _________ mins.
(iv) Own Vehicle _________ mins.

(g) Approximate expenditure incurred on travelling by Taxi/Auto/Bus _______________ Rs./day.

13. Suggest any other facility required for buses on your route.

Thanking you,

Yours sincerely,

(S.P. NAMBALLA)

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